S559143
2

Queensland.

DEPARTMENT OF MINES.

Queensland Geological Survey.

(B. DUNSTAN, CHIEF GOVERNMENT GEOLOGIST.)

PUBLICATION No. 261.

MINES DEPT. NO VICTORIA

# The Arbouin Copper Mines at Cardross

## On the Chillagoe Mineral Field, North Queeensland.

WITH MAP AND ILLUSTRATIONS.

By LIONEL C. BALL, B.E. (Syd.), Government Geologist.

BRISBANE.

BY AUTHORITY: ANTHONY JAMES CUMMING, GOVERNMENT PRINTER.

1918.

# CONTENTS.


PAGE.

I. Introduction—
1 History— .. .. .. .. .. .. .. 3
(i.) Acknowledgments .. .. .. .. .. 5
(ii.) Fieldwork .. .. .. .. .. .. 6
2. Literature .. .. .. .. .. .. .. 6

II. Geology— .. .. .. .. .. .. .. .. 8
1. Pre-Silurian Schistose Rocks .. .. .. .. 9
2. Amphibolites .. .. .. .. .. .. .. 13
3. Silurian Slates and Limestones .. .. .. .. 13
4. Pegmatites (Permian) .. .. .. .. .. 14
5. Elvans (Permian) .. .. .. .. .. .. 15
6. Mesozoic Sandstones .. .. .. .. .. .. 16

III. Ore Deposits—
1. Origin .. .. .. .. .. .. .. 18
2. Lode Channels .. .. .. .. .. .. .. 19
3. Formations .. .. .. .. .. .. .. 19
4. Ore Shoots— .. .. .. .. .. .. .. 20
(a.) Zone of Oxidation .. .. .. .. .. 21
(b.) Zone of Enrichment .. .. .. .. .. 22
(c.) Zone of Primary Sulphides .. .. .. .. 23

IV. Mineralogy—
1. Distribution of the Elements : Aluminium, antimony, arsenic, bismuth, boron, calcium, carbon, copper, fluorine, gold, iron, lead, magnesium, molybdenum, phosphorus, potassium, silicon, silver, sulphur, tin, titanium, tungsten, zinc .. .. .. .. .. .. .. 25
2. Occurrence of Minerals : Arsenopyrite, azurite, bismuth, bismuthinite, bismutite, bornite, calcite, cassiterite, chalcanthite, chalcocite, chalcopyrite, chlorite, clay, cuprite, felspar, fluorspar, galena, garnet, gold, kaolin, limonite, malachite, magnetite, mica, molybdenite, olivenite, pyrite, quartz, rutile, scorodite, stibnite, tetrahedrite, tile ore, topaz, tourmaline, wolframite, water, zincblende .. .. .. .. .. .. .. 28

V. Register of Holdings on the L Line .. .. .. 35

VI. Mining and Transport .. .. .. .. .. 61

VII. Treatment—
1. Ore Dressing .. .. .. .. .. .. .. 63
2. Smelting .. .. .. .. .. .. .. 66

VIII. Production .. .. .. .. .. .. .. 69

# LIST OF ILLUSTRATIONS.


PAGE.

MAP.—Plan of leases on the L line at Arbouin and Cardross, with the more prominent lode and dyke outcrops .. .. .. 36

FIGURES.—

Banded eye-gneiss of the Keppoch .. .. .. .. 11

Basic ore, No. 3 level, Chieftain .. .. .. .. 46

PHOTOS.—

Cardross, viewed from Bonnie Dundee Hill .. .. .. 1

The Walsh River in half flood, showing bed-rock of eye-gneiss, near Cardross .. .. .. .. .. .. 2

Natural exposures of eye-gneiss. Klondyke Creek below the slaughter-yard; and Little Mundiva Creek, Cardross-Mungana road .. .. .. .. .. .. 10

Silurian limestones, near Markham's Caves, half a mile to the north of Mungana .. .. .. .. .. .. 12

Silurian limestones, on Chillagoe road, near Mungana .. 14

Porphyry outcrop, near Mungana .. .. .. .. 15

Mesa of Mesozoic sandstone, lying three miles to the south-east of Cardross .. .. .. .. .. .. 17

Callighan's Range. The Mesozoic sandstone cap, seen from Silver Hill .. .. .. .. .. .. .. 17

Mesozoic sandstones. View Point, near Cardross .. .. 17

Caledonia North and Clansman .. .. .. .. 40

Chieftain Mine, viewed from west, north-west, south-west, and north-east .. .. .. .. .. .. 42

Klondyke and Sink-i-loo .. .. .. .. .. 53

# The Arbouin Copper Mines at Cardross

## On the Chillagoe Mineral Field, North Queensland.

By LIONEL C. BALL, B.E. (Syd.), Government Geologist.

## I. Introduction.

Cardross township is in longitude 144° 20′ east and latitude 17° 10′ south, being 20 miles west of Mungana, the terminus of the Chillagoe railway line, and 149 miles from Cairns, the chief seaport of the Cook district; and it is connected with the railhead by a bush road traversing country which offers no serious obstacles to motor traffic. The population of the town early in the present year was about 100 souls (men, women, and children), but before the outbreak of war it was nearer 300, including the 200 men directly employed in mining.

About a mile and a quarter to the south-south-west of Cardross is Arbouin, the original township, now without population and with scarcely a sign of its former occupation by man. Prior to the laying out of Arbouin the locality was known as Klondyke, after the nearby creek.

CARDROSS.
Viewed from Bonnie Dundee Hill.

The townships and the mines fall within the catchment of the Walsh, on a very old gently undulating surface with a few rounded residuals, rising less than 200 ft. above the general level, and a limited number of mesas, attaining 100 ft. or so more. The river itself occupies a shallow groove in this surface, with a remarkable absence of meanders, of flood plains, and of any alluvial deposits, all pointing, with the frequent rapids, to rejuvenescence.

The mines are badly situated with regard to surface water supply. Klondyke Creek flows for but a few weeks after the wet season; and the small dam on Cardross Gully at the township has little capacity, and is not to be counted on for many months. A plentiful supply might be derived from the Walsh River, in the bed of which there are many permanent waterholes; but fortunately the need to go so far afield has been obviated by the striking of fairly heavy water in the sinking of the Chieftain main shaft—more than sufficient for the townspeople's domestic requirements, for the power plant, and for the ore dressing and reduction works.

THE WALSH RIVER IN HALF FLOOD.
Showing Bed-rock of Eye-gneiss. Near Cardross.

The cupriferous section is without statutory boundaries, it forming part of the Chillagoe mineral field. The principal zone may be said to extend for a mile north of Cardross, three miles east, six miles south, and one mile west, but there are besides several groups of lodes that link it up with the Chillagoe-Mungana copper belt. In the central group are the L and A lines, with to the south-west the Noonday leases and to the south the Spaniard and Mountain Maid. On the road to Mungana are first of all the Laverock group, then the Pandanus Creek group, the Welcome Creek group, and beyond them the mines of Mungana.

## 1. History.*

William Hann, while travelling from the Tate to the Walsh on his exploring expedition of 1872, must have traversed the outskirts of the field, for Mulligan, the explorer, following him, marked a road from the Etheridge to the Palmer Goldfield, and passed within sight of the Mountain Maid cupriferous outcrop, which seems to have been known to many of the Palmer prospectors.

The resources of the district however were undreamt of till 1897, when W. Arbouin and W. Harkins, returning from a fruitless prospecting trip into the country south of Blackdown cattle station, came upon the outcrops of Klondyke. They were so impressed by the possibilities of the many lode outcrops that, on their recommendation, a syndicate styled "Linedale's West Chillagoe Company, Limited," was formed in 1898, and secured a large area of country as mineral leasehold. Mr. Jack, then Government Geologist, who visited the place in 1898, was most favourably impressed with the possibilities of the mines, as noted below. Mr. A. C. Haldane, the Mineral Lands Commissioner for the Herberton mining district, wrote of much recent work in 1898, and of big, bold outcrops with the L line the biggest and richest; and he appended twelve assays to show the general high gold content of the ore raised. The syndicate sank considerable capital, and in 1899 the Warden reported that there was 1,500 tons of ore at grass, principally carbonates, though sulphides were already then being mined, as several shafts had reached a depth of 60 ft. Meanwhile Bedford's Railway and Mines Syndicate had also taken up a few leases, but it passed out without doing any development.

During 1901, the Chillagoe Railway was completed, and the West Chillagoe Company was encouraged to push on the development of its mines in readiness for the early blowing in of the Chillagoe smelters; but no particulars of the early shipments have been recorded. In 1904 Linedale's West Chillagoe Syndicate was merged in the Irvinebank Mining Company, which continued to exploit successfully several leases, the chief being the Lamington, the Macao, and the Laverock. During this period the hand-picked ore was despatched for treatment to the Chillagoe smelters; and it is known that in 1906 the Lamington yielded 400 tons of 17 per cent. copper ore. The company

* For certain of the historical details I am indebted to Messrs W. Atherton, of Chillagoe, and W. Waddell, of Koorboora; but wherever possible the Annual Reports of the Department of Mines have been drawn upon, and, in their stead, the annual statement of the directors of the Mammoth Copper Mines, Limited.

continued to prospect and develop its properties under decidedly disadvantageous circumstances, but ultimately the directors decided to withdraw from the field, because of serious financial complications brought about by the sudden fall in the copper market of 1907.

Already at that time the Mammoth leases on Pandanus Creek, the Mountain Maid on Nonda Creek, and others of the outside leases were being tested by Alexander Macdonald. The Mammoth Copper Mine, Limited, was floated in 1907, primarily with the object of working the mines on Pandanus Creek, but by 1909 the company's operations were restricted to the Mountain Maid. The Scottish North Queensland Exploration Company also was formed in 1909 under Mr. Macdonald's promotion to secure the abandoned leases of the Irvinebank company; and during 1910 work was carried on by it at the Chieftain, Clansman, Caledonia, Caledonia North, and Lochinvar, as the mines were now designated; but the company passed into liquidation in 1911, and the leases were then transferred to the Mammoth Copper Mine, Limited. This company in 1910 had suspended operations at the Mountain Maid, and had transferred its activities to two newly acquired leases, the Keppoch and Allen; and thus in 1911 it controlled all except one or two of the productive mines of the field.

The company's most serious efforts have been directed to the opening up of the Chieftain, where the main vertical shaft has attained a depth of 310 ft. and where much stoping has been done; but the other holdings have not been neglected altogether. From Mr. Robert E. Gardiner, the local secretary, it is learnt that the following sums have been expended on development at the various leases mentioned:—Allan (Albin Macgregor), £5,000; Caledonia, £1,000; Clansman, £5,110; Chieftain, £16,592; Keppoch, £8,000; Lochinvar, £1,000; Mammoth, £2,000; Mountain Maid, £5,600; and Noonday, £3,000; total, £47,302.

In 1911-1912 Mr. Fred. Reid sought to attract capital for the exploitation of some of the outside lodes (including the Spaniard, Sister Maid, Klondyke, Golden Link, and Two Leed Leases), but the projected flotation of the Klondyke Mining Company, by which it was to be effected, was abortive.

The completion of the Mammoth Company's copper blast furnace at Cardross, in August, 1912, opened up vistas of coming prosperity, but the smelting campaign was through in October. Two short campaigns are credited to 1913, and the smelter also ran from June to October, 1915. (I am given to understand

that £12,000 profit was made on this campaign, but that the whole of it was sunk in underground development at the Chieftain.) A concentrating plant was erected by the same company in the middle of 1914, but it was closed down after one month's operation on the outbreak of war in August.

The entry of the British Empire into the European war affected the Mammoth Company disastrously, because of the chief shareholders being absentees. All work ceased immediately, and subsequent trials to make the mines pay their way have served simply to accentuate the need of overseas capital for the efficient conduct of combined mining and treatment. For a time, as during 1915, treatment has been profitably managed; and for a time, as during recent months, the Chieftain has been worked at a profit without the aid of the ore dressing and reduction plant; but in the former case the outside mines and in the latter case the Chieftain distinctly suffered by the depletion of the reserves of higher grade ore and the neglect of development.

The Mammoth Copper Mine, Limited, was formed with a capital of £28,000, which has been gradually increased, till it is now nominally £100,000, exclusive of an advance of £40,000 by the managing director, Mr. Hy. Allen. No dividend has yet been declared. Mr. A. Macdonald tells me that the company has disbursed about a quarter of a million sterling, this including £112,500 derived from sales of ore and matte since December, 1912, and also 120 tons of 18½ per cent. ore, valued at £3,352, shipped during the first quarter of the present year. On this basis it has cost more than £2 to produce each £1 worth of copper—that is, without allowing for ore production prior to 1912, which cannot appreciably mitigate the seriousness of the position. In June last the company's activities were confined to the Chieftain, where six men were employed underground. An average of 25 tons of ore was being hauled per day; and 100 tons of hand and machine dressed ore was being despatched by traction engine to the railhead each month.

*Acknowledgments.*—My thanks are due to various officials of the Mammoth Copper Mine, Limited—Messrs. Alex. Macdonald, F. Reid, R. E. Gardiner, P. Ahern, E. Markham, and J. O. Christian—who, besides facilitating my investigations, helped to make my visit to the camp one to remember with pleasure. The brunt of the field assistance fell upon Mr. Reid; and I should here mention that my inquiries were much simplified by the management lending me Messrs. N. and F. Reid's sketch map, recording production of the various mines, and also numerous plans of underground workings.

*Fieldwork.*—During my stay in the district, protracted over a period of six weeks in May and June last, most attention was given to the L line, which latter with all its branches was plotted on a scale of 2 ch. to an inch. Underground plans of the Chieftain, on a scale of 20 ft. to an inch, based on the company's surveys, were prepared for the reception of geological features. Cursory visits only could be paid to the outside lines, but most of them have been plotted on a scale of 8 ch. to an inch. Fieldwork was much retarded by a luxuriant growth of grass, due to the recent unusually heavy wet season.

## 2. Literature.

G.S.Q. publication No. 69 (1891). Report on the Chillagoe and Koorboora Mining Districts. Mr. Robert L. Jack, Government Geologist, deals with the country as far west as Mungana. The limestones are mapped as Carboniferous.

G.S.Q. publication No. 119 (1897). Report on the Tin Mines of Watsonville, and various silver, copper, and gold mines at Herberton, Montalbion, Calcifer, Chillagoe, California Creek, the Tate River, &c. Mr. Sydney B. J. Skertchly, Assistant Government Geologist, does not treat of the country further west than Mungana; but on the map he shows the limestones as Devonian (?) and the country beyond to the south-west as "schist."

G.S.Q. publication No. 119 (1897.) Report on the Tin Mines Mining District and Projected Railway. Mr. Jack speaks in enthusiastic terms of the prospects of the Arbouin mines, and advocates an extension of the Chillagoe Railway thereto. He speaks of the ore deposits occurring in "true lodes," exceptionally wide and persistent, which show on the surface a quite unusually large quantity of copper ore. He notices also that the ores invariably yield a fair prospect of gold, enough to be a distinct advantage in a milling ore and to prove most welcome at the smelting works. Gneiss and schist are stated to occur all around the camp (Arbouin) and mines, and denuded ranges of Desert Sandstone to the south of the Mungana road are mentioned. The various lodes then being exploited are referred to with brief detail, and there appear the names of the Lamington, P.P.A., Ladrone, Lebanon, Leghorn, Leicester, Macao, Lytton, Leviathan, Arrowsmith, Big Blow, Argosy, Perseus, Apollo, Dominion, Great Seal, Yankee, Aurora, Nondah, and Spaniard.

G.S.Q. publication No. 150 (Ann. Rep. Dep. of Mines for 1899, p. 148). Visit to the Chillagoe District. Mr. B. Dunstan,

Assistant Government Geologist, refers in passing to the Royal Standard and the Admiral Sampson mines, the former in the Mungana and the latter in the Cardross district.

G.S.Q. publication No. 159 (Ann. Rep. Dep. of Mines for 1900, p. 196). Some Chillagoe geological notes. Mr. Dunstan describes the radiolarian cherts, quartzites, and limestones of Belgravia, near Redcap, the Halysites limestones of Mungana, and the intrusive granites with their modifications.

G.S.Q. publication No. 190 (1904). On the occurrence of the Genus Halysites in the Palaeozoic rocks of Queensland and its geological significance. Mr. R. Etheridge, jun., describes a new species, H. Chillagoensis, from Mungana, and assumes the age of the limestone to be Silurian.

N.S.W. Palaeontology, Monograph No. 13 (1904). Silurian and Devonian corals of New South Wales. Part 1, The Genus Halysites. Mr. Etheridge refers to Halysites Chillagoensis and submits illustrations (omitted from the official descriptions).

G.S.Q. publication No. 187 (1904). Sketch map of the Walsh and Tinaroo Mineral Field, 2 miles to an inch. Mr. Walter E. Cameron, B.A., Assistant Government Geologist, includes Arbouin in his map and roughly indicates the positions of the Lamington and Spaniard lodes. The country is shown as gneiss and schist with doubtful areas of Desert Sandstone.

Proc. Roy. Soc. of Q., Vol. XXII. (1908). Chillagoe Garnet Rock. Mr. Frank E. Connah chemically determines the garnet of Mungana to be lime-iron-alumina silicate.

G.S.Q. publication No. 231 (1911). The Lower Palaeozoic Corals of Chillagoe and Clermont. Mr. Etheridge describes Cyathophyllum Dunstani, C. Chillagoensis, and Spongophyllum "from the belt of limestone about three miles to the south-west (?north-west—L.C.B.) of Mungana."

Prospectus of the Klondyke Copper Mines, N.L. (1913). This contains a brief report by Mr. R. L. Shepherd, consulting engineer, descriptive of the Klondyke, Golden Link, Spaniard, Leed, and Sister Maid leases and the Valley claim, with respect to their future exploitation. The report is accompanied by a longitudinal section of the Spaniard lode.

# II. Geology.

The Cardross area is one essentially of schist and gneiss, interspersed with pegmatite. The newer Silurian limestone series of Chillagoe-Mungana is missing, but we have outliers of a much younger Mesozoic sandstone capping parts of the field.

Skertchly (in G.S.Q. publication No. 119, p. 5) refers the igneous rocks of the old Walsh and Tinaroo mining districts to four periods: that of the granites (newer than the Permo-Carboniferous ? or Devonian ?) that of the great porphyry series (which intruded the granite), that of the elvan dykes (which intersect alike the sedimentary rocks, the granite, and the porphyries), and that of the basic dykes; and he claims that the two latter are closely connected with the production of the tin-bearing lodes. We may now add that they are related genetically to the copper deposits between Mungana and Cardross, for though granite is wanting we have a widespread series of elvan dykes, intimately associated with which are the richer copper-bearing shoots of the field.

The schists support a rather stunted growth of various hard-woods, among which eucalypts (messmate and ironbark) and the poison ironwood (Erythrophloeum) predominate, with quinine and wattle. Varieties of melaleuca, mostly of small size, abound on the flats and depressions and also on those slopes that during the wet season become quagmires; while in the sandy beds of the creeks pandanus flourishes. Bloodwood (Eucalyptus corymbosa) is chiefly restricted to the lode outcrops—a peculiarity, known to the antimony miners as well as the copper prospectors of North Queensland, of which I have myself made many confirmatory observations. The preference is not due to the presence of the metallic ores, but to water trapped in the lode channels within reach of the tree roots, for, between the copper and antimony fields, bloodwood thrives on the lower slopes of the water-bearing sandstone mesa of Mount Mulligan, but fails completely in the slates of the Hodgkinson valley, except along the outcrops of the antimony lodes.

The sandstone mesas to the south-east of Cardross have quinine, gum, and ironbark on the plateau, ironwood fringes the base of the cliffs, and stunted ironbark grows on the lower slopes with an occasional bloodwood. The Sand Ridge on the Mungana road, a remnant of a former mesa, carries a luxuriant growth of ironwood, box, gum-topped box, and bloodwood, with glossy leaved scrub-whitewood and stringybark, but quinine is quite wanting.

The timbers of the schists suffice for boiler fuel, for charcoal making, and for ordinary underground supports; but, in the

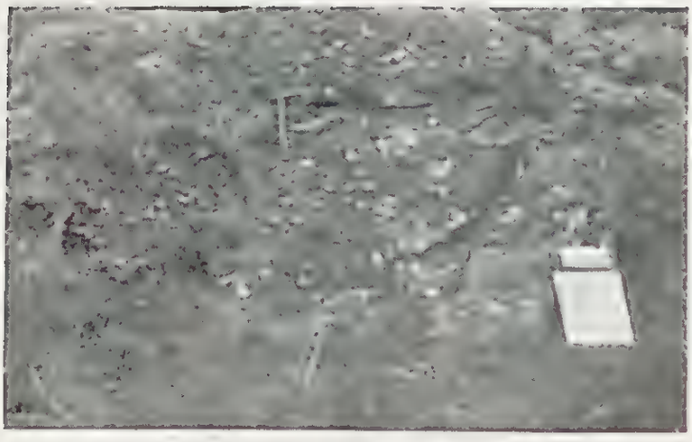
absence of river alluvials capable of sustaining trees of large size, the less accessible sandstone country with its stronger growth has to be drawn upon when special sizes are required.

### 1. Pre-Silurian Schistose Rocks.

Schists and gneisses form a fundamental complex of wide extent, having been observed as much as 20 miles to the south-south-east of Cardross. To the south and south-east they pass under the mesozoic sandstone plateau, but they stretch out eastward almost to Mungana and Chillagoe, where they rather abruptly give way to hard massive slaty rocks. While not very specific on the point, Jack seems to regard the schist and gneiss of Dargalong (belonging to the same belt as Cardross) as the highly metamorphosed equivalent of the Chillagoe slates and limestones to which he first attributed a Carboniferous age (G.S.Q. publication No. 69, p. 2). Skertchly (in G.S.Q. publication No. 119, p. 5) agrees with Jack in looking upon the schist and gneiss to the south of Chillagoe as highly metamorphosed sedimentaries, but he classes them as probably Devonian in age. In my own opinion the abruptness of the change from the relatively unaltered Silurian slates and limestones of Chillagoe and Mungana to the gneisses and schists of Dargalong and Cardross should suffice, in the absence of further evidence to the contrary, for their relegation to an earlier period. The general absence of garnet from the metamorphics alone should warrant their complete separation from the aluminous and calcareous Silurian strata.

True mica schist almost wholly made up of lamellar muscovite with only rare lenses of quartz is not uncommon, and we also find a biotite-quartz rock, but quartz and felspar frequently predominate over the mica. In places the rock, though still highly schistose, is composed chiefly of quartz, such as the granular quartz-rock of the Mountain Maid, rendered conspicuous by scattered ½-in. diameter hexagonal flakes of muscovite and an odd crystal of tourmaline. These rocks weather down into rather sandy soil, and they seldom outcrop because of their inferior hardness as compared with the associated gneiss. As noticed elsewhere, the schists in many parts are intensely seamed with pegmatite, probably the product of magnetic intrusive emanations.

While recognised as being closely allied to the schists, and as in all probability representing highly metamorphosed sedimentary rocks of great age, the mostly dark coloured, crystalline, and less schistose rocks may be distinguished under the caption of gneiss. They consist of granular felspar and quartz, with ferromagnesian mineral sufficient to shadow the lines of schistosity, but by the local disappearance of the mica we find occasionally an aplitic type. Thus the rock at the Noonday presents a granular mixture of quartz and white felspar (as $\frac{1}{20}$ in. grains), with a sprinkling of muscovite (in $\frac{1}{30}$ in. spangles).

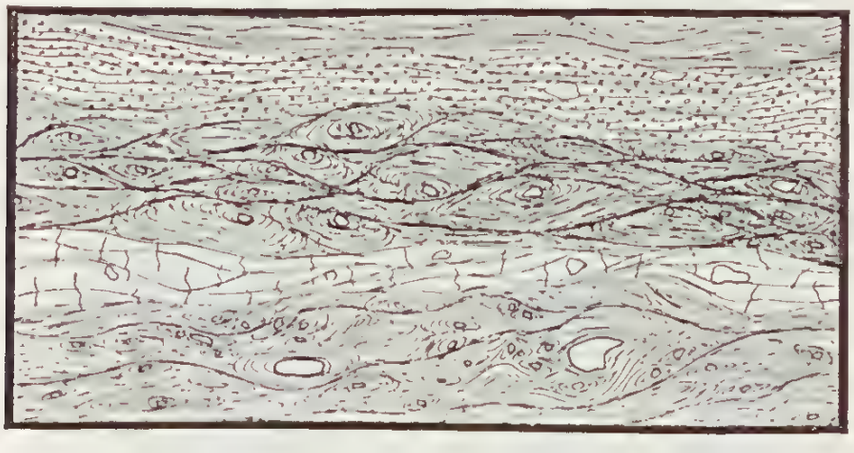


NATURAL EXPOSURES OF EYE-GNEISS.

Klondyke Creek, below the Slaughter-yard: and
Little Mundiva Creek, Cardross-Mungana Road.

At the surface the felspar is completely kaolinised, but the muscovite is not altered, though most of it is surrounded by a slight staining of iron-oxide. In some parts the felspar seems to have been removed, and we have, as at the Mountain Maid, a granular quartzose rock with scales and books of muscovite plentifully distributed, though by actual percentage insignificant. In the lode formation at depth on the Chieftain, the rock is impregnated with sulphides and sulpharsenides, the felspar has suffered kaolinisation, and the quartz has become more prominent, while the chloritisation of the mica has intensified the schistose structure.

The most conspicuous sub-type is eye-gneiss, which is of wide occurrence and crops out in every section of the field visited. It has a granular quartz-biotite-felspar base, is black to dark blue-grey in colour, and is more or less distinctly banded in structure; but its special feature is the oriented "eyes" or rounded lenticular masses of various sizes and abundance. These consist chiefly of felspar—usually a single crystalline mass or twinned crystal without sharp outlines; the mineral at a depth is milky white, but exposure at the surface induces a pink tinge; both single and multiple twinning have been observed, the latter rarely; and the presence of plagioclase is suspected as well as that of orthoclase. In the bed of the Walsh River, one of the best spots for observation, the crystalline granular quartz-felspar-biotite rock is very variable in composition and structure, there being zones up to 50 ft. across, with well developed felspar eyes (mostly 1 to 3 in. in diameter), and seams only of finely crystalline granular rock; but there are also rapidly alternating



Banded Eye-Gneiss of the Keppoch (One-quarter Natural Size).
Coarse, Quartzose, Fine, Felspathic, and Micaceous.

thin bands of the two species. The schistosity is pronounced, and here trends north to south, with a 1 in 1 dip westerly. At the Walsh there are exposed also some few elongated masses of quartz up to 6 in. in diameter, and there are 1 in. veins of the same mineral.

SILURIAN LIMESTONES.

Near Markham's Caves, Half-a-mile to the north of Mungana.

### 2. Amphibolites.

Hornblende schists, grading into granular diorites, are known to occur in quantity immediately to the south-west of the Silurian belt of Mungana and Chillagoe, and such were observed also on the Mungana-Cardross road between Spring and Welcome Creeks, but in the vicinity of Cardross itself schistose hornblendic rock was noticed in only one place, *i.e.*, on the Plum-tree crossing, where the rock consists essentially of a dark green hornblende with perhaps 20 per cent. felspar and traces of pyrite.

On Klondyke Creek, below the slaughter-yard, a mass of very fine-grained diorite is exposed, with pyrite present as traces. Weathered boulders of a dark coloured granular rock, possibly a diorite, have been found along the eastern edge of the big felsite dyke in M.A. No. 63; and dyke masses occur also in the gneiss of the Walsh River near Cardross. These last are angular blocks, as much as 3 ft. in diameter, of a very fine-grained black rock speckled with $\frac{1}{10}$ to $\frac{1}{20}$ in. crystals of felspar; and they represent either broken up dykes or fragments of highly metamorphosed calcareous strata.

### 3. Silurian Slates and Limestones.

Unaltered slates and limestones do not occur at Cardross, the nearest being at Mungana, and them I regard as distinctly newer than the gneisses. It is necessary, therefore, to present in full the evidence bearing on the age of the limestones.

In 1891, Jack, for want of any fossil evidence to the contrary, regarded the stratified rocks of the Chillagoe district, including the limestones, as of the same age as the Hodgkinson beds—*i.e.*, Carboniferous (G.S.Q. publication No. 69, p. 3). When Skertchly wrote in 1896 (G.S.Q. publication No. 119, p. 5), the sandstones, grits, conglomerates, greywackes, shales, and slates, with the limestones of the Chillagoe district had as yet yielded only a few obscure corals and polyzoa, and consequently their age had not been established; but they had been referred provisionally to the Carboniferous, and were thought possibly to belong to the Devonian. Writing in 1898 (G.S.Q. publication No. 134), Jack reduced the sedimentary rocks "limestones, mica schists, garnet rock, etc." of the Chillagoe district to the Devonian on unspecified palaeontological evidence to hand.

In 1900, Mr. B. Dunstan, then Assistant Government Geologist, announced the discovery of Halysites in the limestones of Mungana, and he consequently was inclined to regard them as of Silurian age. He described also radiolarian cherts and quartzite, associated with more or less altered limestone at Belgravia, west of Redcap. Subsequently, in 1904, Mr. R. Etheridge described fossil specimens from the limestones south-west of Mungana, naming them Halysites Chillagoensis. Believing

SILURIAN LIMESTONES.
On Chillagoe Road, near Mungana.

Halysites to be restricted to the Ordovician and Silurian systems, he supported Mr. Dunstan in regarding the limestones as of Silurian age; and, in his bulletin of 1911 (G.S.Q. publication No. 231) descriptive of Cyathophyllum Dunstani, C. Chillagoensis, and Spongophyllum from the Mungana limestones, he definitely refers them to the Silurian.

My own discovery of abundant Favosites, Heliolites, Cyathophyllum, Campophyllum, Halysites, etc., with Rhynchonella, and Pentamerus in the limestones at Mungana and Chillagoe, will probably go to substantiate this decision.

### 4. PEGMATITES (PERMIAN).

Pegmatitic masses occur in the schists and gneisses at numerous scattered localities. They may be referred to the Permian in conformity with the classification of the chief granitic areas of the northern part of the State.

The pegmatites may be regarded as the final segregation products of the first intruded portion of an acidic magma, lying at a depth below the surface, the elvans and the ore deposits being products of segregation from the still deeper part of the same magna that solidified somewhat later.

At the Noonday the rock has been found in a fresh condition; and it consists of intercrystallised milky-grey quartz and flesh-coloured felspar (the latter in masses up to 1½ in. in diameter, and only slightly less plentiful than the former), with rather crushed book spangles of muscovite up to ½ in. in diameter occurring in both felspar and quartz, but preferably in the latter. Between the township of Cardross and the smelter site on the eastern side of the Leicester is one of the most conspicuous crops, mainly of felspar and granular mica, with a little quartz. At the town well is granular micaceous gneiss with defined coarsely pegmatitic bands, but a few chains to the south the pegmatitic crystals and bunches lose their sharpness. Many

other outcrops of pegmatite are in evidence along the eastern side of the L leases, and it is possible that the occurrence is not altogether accidental, though no direct connection with the ore bodies has been made out.

### 5. Elvans (Permian).

A well-marked system of elvan dykes is developed in the Cardross-Mungana mineral area. To the west of Mungana there is a large intrusive mass of porphyry, on the periphery of which are several copper deposits (the Ben Nevis, Jubilee, etc.); but the dykes of Cardross are mostly of small size, only exceptionally swelling to a width of 20 ft., and they are typically discontinuous, while some of them are traceable on the surface for only a few yards. Along the L line of leases some of the dykes trend north and south, and others east and west, but in the central area the general aspect is north-west to south-east—at right angles to the lode formation. In rare instances these dykes have been faulted, such seemingly being the case at the Keppoch, but in the Chieftain and others it is the lode that has suffered dislocation.

Porphyry Outcrop, near Mungana.

The close interdependence between the dyke rocks and the ore-bodies is clearly indicative of some genetic connection. Thus we note that all the more important ore-bodies and most of the workable deposits are in the immediate vicinity of dykes, and at the two most productive mines are the largest dyke masses. Conversely, where the dykes are wanting the formations are wont to be barren or low grade, and, further, in few instances have dykes been observed in altogether unproductive country. I take

it that the elvans represent a late phase of the hypothetical granitic intrusion already mentioned, and that their injection was shortly followed by the pneumatolytic emanations giving rise to the ore deposits.

The dyke rock varies from quartz-felspar-porphyry through felspar-porphyry and quartz-felsite to felsite. At the outcrop, the felsitic groundmass is usually cream-coloured, or it is pinkish where slightly altered, but where completely kaolinised, as at the Chieftain and Herd Lassie, it is dull brick-red and earthy. In certain cases the base has undergone chloritisation, and appears as a dull blue-grey earth—*e.g.*, in the underground workings on the lode formations of the Spaniard and Clansman. Pyrognostic tests reveal traces of boron in the altered dyke rock both at the crop on the Chieftain and below ground in the Spaniard; and this points to kaolinisation having taken place under hydato-pneumatolytic and not simple atmospheric conditions.

The rock from No. 3 level in the Chieftain is a dark bluish-grey fine-grained felsite, with few quartz phenocrysts. The quartz phenocrysts—bi-pyramidal crystals sometimes slightly corroded—vary in size from $\frac{1}{50}$ in. to $\frac{1}{10}$ in. diameter, and may be spaced anything up to ½ in. apart. The lath-shaped felspar phenocrysts are less easily distinguished and are seldom more than $\frac{1}{20}$ in. long, never plentiful, but frequently kaolinised. A rare flake of biotite $\frac{1}{40}$ in. in diameter has been observed in one or two specimens. Of secondary minerals the earthy chlorite has already been mentioned, this being an alteration product of the ferric and salic constituents of the rock, but there are also introduced minerals: quartz (as thin stringers) and pyrite (in grains and seams). For ¼ in. on either side of the ¼-in. vein of quartz, the rock is noticeably darker than elsewhere. Until lately it had been regarded as everywhere barren of copper sulphides, and therefore, perhaps, of more recent date than the ore-bodies; but rich veins and stringers of chalcopyrite are now being exploited above No. 3 level in the Chieftain within the dyke-rock proper.

### 6. Mesozoic Sandstones.

The sandstones capping the hills to the south of Cardross are of medium grain on the whole, though there is an occasional pebble band. Current bedding is pronounced. No fossils have yet been discovered in these beds, perhaps because of the absence of shale bands; but on stratigraphic grounds they are classed as of Mesozoic age.

Mesozoic Sandstones. View Point, near Cardross.

Mesa of Mesozoic Sandstone. Lying 3 Miles to the South-east of Cardross.

Callighan's Range. The Mesozoic Sandstone Cap, seen from Silver Hill.

# III. Ore Deposits.

The ore deposits of Cardross are on the whole neither very high grade nor of very great size. Rich shoots of ore seldom crop out at the surface, and the few found have not been of startling magnitude; but the medium to low-grade formations are persistent, and their commercial development and exploitation, on which the future of the field depends, can be facilitated by a full discussion of all conditions of occurrence and origin.

## 1. Origin.

The more one learns of the Arbouin lodes the more difficult it becomes to explain them as other than very irregular composite fissure systems, with ore shoots due to pneumato-hydato-genetic action in the vicinity of cross fractures occupied by elvan dykes. There is morphological and mineralogical evidence to show that the ores were brought in by the final pneumatolytic emanations of a deep-seated granitic magma. Thus the absence of crustification in the ore-body and the presence of a coarsely crystalline massive texture are indicative of formation at high temperature and pressure in genetic connection with intrusive rocks. Moreover, the presence of magnetite in association with pyrite, chalcopyrite, and arsenopyrite in the Chieftain ore-body brings them into close relationship with the group of contact deposits, and the discovery on the field of tourmaline, fluorspar and topaz, and wolfram, containing the mineralisers boron, fluorine, and tungsten, points still more conclusively to proximity to the parent magma. That the ore-bodies are wholly encased in gneiss and schist and occupy lode fissures would seem to be in no wise contradictory, for they may still be the offshoots of contact deposits and come under the type described as apo-magmatic. Following a recent suggestion of Graton, we may assume also that the hot metal-bearing solutions, by reason of their expansive force, opened the fissures as required and deposited the ore minerals partly directly in consequence of loss of pressure, and partly indirectly in place of rock silicates dissolved.* The favourable influence exercised by the elvan dykes on the development of the ore shoots has already been touched upon; and it is suggested that the escape of the last of the magmatic emanations containing the metals would necessarily have been from

* Ore Deposits. W. Lindgren.

foci or fractures in the cooled granite already discovered by the elvans; but that, in forcing their way upwards through the gneiss they would follow lines of least resistance and enter any other fissures available.

Thus the miner need fear no sudden or complete disappearance of the ore deposits within the schists. Below them, in the absence of limestones, it is unlikely that there are deposits comparable in size with those of Chillagoe at the intrusive granite contact; but it is possible that in the granite the copper lodes may give place to tin greisens.

### 2. Lode Channels.

The L line, that most closely studied of the many in this district, is a lode system with the commercially valuable ores occurring bunched at intervals in an enmeshed series of fissures. In its southern part it is simple; but towards the north it branches, and we have a network of intersecting veins and formations, with a general westerly underlie. The line as a whole strikes obliquely to the trend of the gneisses and schists.

The fissures in places are simple and clean cut, with unaltered and fresh wall rocks; but commonly along them the adjacent country has suffered chemical and mechanical change —the latter the result of shearing and crushing forces, the former of action by the magmatic solutions. This altered material is known to the miners as formation, and it is sought by them as the locus of ore shoots.

### 3. Formations.

"Formation" is the miners' term for the crushed and altered material—often micaceous and frequently kaolinised or silicified and sometimes mineralised—occurring within and along the lode fissures, the result partly of mechanical and partly of chemical action. Some of it is so highly micaceous as almost to fall within the definition of greisen (see Bonnie Dundee and Mountain Maid). At the opposite end we include with formation the hard crystalline mica- and felspar- bearing rock with stringers of chalcopyrite and bunches of magnetite adjacent to the ore shoots proper, in the lower levels of the Chieftain. In others there has been slight kaolinisation of the felspars and chloritisation of the mica; but the formations usually are highly siliceous, partly because of the primary quartz contents and partly owing to a secondary deposition of vein quartz. The biotite may have disappeared, but in its place are a few silver-white spangles of muscovite. Lastly impregnations by sulphides, especially

arsenopyrite, are seldom absent, and exposure to atmospheric influences has given us the greenish arsenical outcrops so typical of the district.

The ordinary formation of the Chieftain is kaolinised and slightly chloritised gneiss, but we also find a finely granular and highly siliceous replacement of this rock. In depth it is almost everywhere impregnated by arsenopyrite in distinct crystal grains, it may be of no more than $\frac{1}{50}$ in. in diameter; but pyrite also is present in some. Chalcopyrite, too, renders it a low-grade ore, with, perhaps, 3 per cent. copper. The mineral occurring in some places in granular aggregates up to $\frac{1}{10}$ in. in diameter and in others in minute filigree form. At No. 3 level it exhibits a decided preference for the quartz of the more siliceous formation. At the surface there are, of course, gossany seams (with traces of chalcocite), besides much greenish scorodite and some yellow-green olivenite so characteristic of the outcrops, but azurite and malachite are confined to stains on cracks.

The separate formations have seldom been shown in the underground workings to be more than 20 ft. wide; but, grouping the outcrops, we have several of much greater size, and it might be said that, in the case of the Chieftain, formations extend with included bands of schist from the smelter to Petersen's house, 11 chains to the west-north-west.

The outcrops of the formations with few exceptions are the reverse of encouraging to the prospector enamoured of the iron cap; and it is doubtful if, but for the relatively high gold values, any sinking would have been done on the arsenical formations. Developments at the Chieftain, however, may well induce mining speculators to undertake deep sinking on some of the other formations, which hitherto have been looked upon as altogether without promise.

### 4. Ore Shoots.

The ore shoots consist of important aggregations of the metallic minerals, brought about within the formations. The longest in the Cardross district are those of the Chieftain (600 ft.), the Clansman (200 ft.), the Spaniard (200 ft.), and the Noonday (200 ft.), respectively 6 ft., 3 ft., 2 ft., and 4 ft. in average width. The stope plans of the Chieftain and Clansman support the contention of the management that the shoots pitch flatly southwards along the westerly dipping lode channel; and this may serve as a criterion in prospecting for cupriferous sulphides on the Bonnie Dundee, besides explaining the failure of the Mammoth company to locate a shoot directly below the fine-looking arsenical crop on that lease.

Exceptionally the shoots are made up of chalcopyrite with a little granular chlorite, but usually in the Chieftain we have a mixture of chalcopyrite, pyrite, magnetite, and arsenopyrite in variable proportions. The ores of the Cardross district mostly carry fair gold values, frequently ½ oz. and sometimes 1 oz. per ton. All are high in arsenic and silica, and indeed the latter is the stumbling block in the way of their profitable local reduction by smelting, under the existing high cost of getting fluxes.

The changes due to exposure to meteoric solvents above ground-water level will be dealt with below, these including oxidation of the primary sulphides with the production of oxides, carbonates, and secondary sulphides. Among the last we should, perhaps, include with chalcocite part at least of the chalcopyrite occurring just below water level and at greater depth along the dykes. The three zones common to most ore deposits—that of oxidation, that of enrichment, and that of the primary sulphides —are well marked.

### (A.) ZONE OF OXIDATION.

We have, on the L line, an almost barren weathered zone, extending from the surface to a maximum depth of 100 ft., where it is sharply marked off from the underlying secondarily enriched ore. The reason for this is that the copper of the original chalcopyrite, oxidised in the presence of pyrite and in the absence of alkaline carbonates, has passed into solution as sulphate, and so has been carried down into the standing ground-water. The appearance of olivenite in the crop is due to reaction between the copper sulphate and iron arsenate, an oxidation product of arsenopyrite associated with the chalcopyrite.

The shoads from the lode outcrops are well rounded on account of long exposure and the relative softness of the constituent limonite. They exhibit only traces of copper carbonate or arsenate on the exterior, but are easily distinguished from country rock. A fine gossan was observed in small quantity at the Scallwag, where stalactitic limonite with a lustrous black and iridescent coat is attached to an extremely fine earthy cellular brick-red gossan, veined with platy seams of crystalline azurite and thinner threads of earthy malachite.

The characteristic surface ore of copper is not a carbonate but an arsenate—usually a greenish-yellow earthy ore, but it occurs also as an olive-green crystalline mass shading off into pale greenish-blue scorodite. The oxidised ore in the Allan workings on the Albin Macgregor is a soft dark reddish ferruginous earth, veined and impregnated with the yellow-green arsenate.

My assays prove that the richest of the crystalline material carries about 12¾ per cent. of copper. Quantities of the ore have been treated at the Chillagoe smelters as "carbonates," though the company's assay books record 3 to 14·5 per cent. arsenic with 6 to 20 per cent. copper in consignments received. It is probable also that the "phosphate" raised from the Leicester (Chieftain) in 1898, containing 12·4 per cent. copper, with 4 dwt. silver and 6 dwt. gold per ton, was really arsenate.

The oxidised ore at the Mountain Maid has a tourmaline bearing, cellular, gossany matrix, in which malachite occurs as thin stringers, while azurite prefers the open cavities. More commonly, as at the Clansman, the oxidised ore consists of a dense brown limonite base containing disseminated azurite and malachite, with a small quantity of chalcocite. The rich carbonate ore of the Noonday has a massive brownish limonite matrix, with granular masses of brick-red tile ore. Malachite shows as thin stringers in the dense limonite and azurite as ¼ in. crystalline bands filling open seams. The metallic streak indicative of the presence of chalcocite can usually be produced in these ores, though the mineral may be otherwise not distinguishable by the naked eye. Quartz is always present, and the rich cupriferous limonite at the Keppoch is characterised by quartzose bands. The high "insoluble" in most of the analyses quoted below is to be ascribed to this mineral. Bismuth is believed to be widespread in its occurrence; and zinc is to be found in small quantities, when sought.

The comparatively high gold and silver contents of the oxidised ores of this field was evident to the prospectors from the first. Thus the Macao (Chieftain) gossan, containing only 0·8 per cent. copper, carried 5½ oz. silver and 13 dwt. gold per ton; and a 3-ft. seam of tile ore and carbonates assayed, with 25·7 per cent. copper, 2¾ oz. silver and 15 dwt. gold per ton. The tile ore of the Ladrones, Lebanon, and Leghorn, with 13 to 18 per cent. copper, gave assays of 2 to 7¾ oz. silver and 4 to 8 dwt. gold per ton. The Spaniard seems to have been a marked exception, for ore, assaying 23·8 per cent. copper and 3 oz. silver per ton, carried no gold.

### (B). ZONE OF ENRICHMENT.

Enrichment is brought about in the upper regions of the standing ground-water by the action of descending solutions of copper sulphate, firstly, upon chalcopyrite with the production of covellite and chalcocite, and, secondly, upon pyrite with the production of chalcocite and exceptionally of bornite and chalcopyrite. The zone of enrichment is of uncertain depth at Cardross, but probably as a whole it does not reach more than 50 ft. below ground-water level; and yet secondarily enriched ore was observed as far down as No. 3 level in the Chieftain,

where the massive yellow chalcopyrite contains small ($\frac{1}{4}$ in.) grains of chalcocite. Part at least of the massive chalcopyrite occurring just below water-level and at greater depths along the dyke may also be of secondary origin.

The enriched ore varies slightly according to the nature of the deposit. That from the 35-ft. level in the Clansman has a chloritic groundmass with embedded chalcopyrite and chalcocite; and the ore raised during December, 1913, had the following composition:

Cu, 20·5 %; Ag, 9 oz. per ton; Au, 11 dwt. per ton; FeO, 47·7 %; $SiO_2$, 2·6 %; $Al_2O_3$, trace; S, 32·1 %.

At the 100-ft. level in the Albin Macgregor, the limonite base has irregularly shaped patches of pyrite and indefinite impregnations of massive chalcopyrite. The semi-oxidised formation of the Noonday is kaolinised gneiss with disseminated primary arsenopyrite and chalcopyrite, besides some secondary chalcocite and a staining of malachite. The enriched sulphide ore of the same lode consists of massive chalcopyrite with some arsenopyrite and irregularly branching masses of metallic chalcocite, but thin veins of malachite are not altogether wanting. At the Spaniard and Devon we have massive chalcopyrite stained and veined or minutely netted with massive and earthy chalcocite.

### (c.) ZONE OF PRIMARY SULPHIDES.

In the zone of primary sulphides the ore is beyond the reach of oxidising surface waters, and its composition varies from point to point only in conformity with fluctuations in the conditions existing during deposition from the first uprising solutions. It may not be noticeable over moderate intervals, but we must expect to find a very slight falling off in the copper-gold-silver values with greater depth where higher temperatures and pressures prevailed, both adverse to precipitation.

The sulphide ore at the Noonday is an intimate mixture of branching yellow chalcopyrite and crystalline iron-black arsenopyrite, the latter enclosing crystals of pyrite up to $\frac{1}{4}$ in. in diameter. The dense chalcopyrite of the Laverock also, besides pyrite, contains inclusions of arsenopyrite, especially in the vicinity of the siliceous formation, which in parts contains no other metallic mineral. Similarly, at the opposite end of the field in the Mountain Maid, the low grade, finely granular, highly siliceous matrix contains finely disseminated chalcopyrite, mostly less than $\frac{1}{20}$ in. in diameter, and arsenopyrite, but the latter is in crystalline grains up to $\frac{1}{4}$ in. in diameter. At the same mine the ordinary sulphide ore is a dense chalcopyrite with irregular inclusions of quartz and a little pyrite. The constant presence was noticed of black tourmaline, the fine rays of which sometimes continue individually far out into the surrounding sulphide.

The mixed sulphides of the Caledonia North have a base of dull massive pyrite, carrying chalcopyrite associated with which is a little galena and some blende. The Trojan, one of the western lines, is a highly siliceous lode, with crystalline quartz irregularly veined by yellow chalcopyrite, and tarnished bornite and sparsely impregnated with granular pyrite.

The sulphide ore of the Chieftain has several specially interesting features. That occurring in close association with the felsite dyke is essentially a massive, rather pale-coloured chalcopyrite, but through it there are scattered $\frac{1}{16}$ in. ragged nests of a dull pyrite, and there are also thin irregular veins and drusy crystals of the same mineral; there are some small pellets of a silver-white arsenopyrite; and there are thin seams of pyritous earthy chlorite, which give rise to a banded structure. Fairly evenly distributed through some of the chalcopyrite are small irregularly shaped rosettes of the same dull earthy chloritic mineral; but again chalcopyrite from the same face and separated from the above by only a $\frac{1}{4}$ in. band of pyrite may be almost free from the chlorite; and, moreover, dissolution of the chlorite has taken place in parts of the ore-body, leaving cellular chalcopyrite.

Magnetite, as rounded masses up to an inch in diameter, is abundant in the sulphide ore, but most plentifully at a distance from the dyke. In places the magnetite and chalcopyrite are in separate agglomerations, in others they are intimately mixed, and in still others their banding has the effect of a slightly schistose structure. In ore from No. 3 level, the chalcopyrite and magnetite are intergrown, straight threads of magnetite passing outwards into the massive chalcopyrite, while fine anastamosing veinlets of chalcopyrite penetrate the outer part of the magnetite. The "grizzly ore" at this level assays about 7 per cent. copper, and is so called because of its need for treatment by milling; it has a roughly banded structure due to $\frac{1}{8}$ in. bands of pure sulphide in a quartzose, pyritic, magnetite-bearing base. The analysis of ore used in the jigging experiments of January, 1914, is probably representative of this class:

Cu, 6·8 %; Ag, 3 oz. per ton; Au, 0·5 dwt. per ton; FeO, 28·4 %; $SiO_2$, 36·1 %; CaO, —; $Al_2O_3$, 15·4 %; S, 12·6 %; total, 99·3 %.

This leaves room for arsenic, though a larger quantity might have been expected.

The high grade of the sulphide ore has been known since the earliest years of the field, and already, in 1898, the Mineral Lands Commissioner quoted an assay of Macao sulphide with:

Copper, 21·6 %; silver, 2·7 oz. per ton; and gold, 10 dwt. per ton.

# IV. Mineralogy.*

Before describing the various minerals of the ore-bodies, it may be of service to review them under their predominating metal or the essential non-metallic constituent.

## 1. Distribution of the Elements.

*Aluminium.*—This metal is an important constituent of the primary and altered silicates of the country rocks and of the formations. The proportion also in the ores has been great enough to warrant the assayer notifying the metallurgist of the amounts, as seen in several instances below.

*Antimony.*—In combination with copper and sulphur, the metal has been said to occur in the Cardross lodes as tetrahedrite, but the mineral so diagnosed was in all probability the simple copper sulphide, chalcocite, for antimony has not been recorded in any of the company's analyses. The sulphide, stibnite, is reported to exist in lode form near Callighan's Springs.

*Arsenic.*—The element is found both in the oxidised state, as arsenates of iron (scorodite) and copper (olivenite), and in the unoxidised condition, as sulpharsenide of iron (arsenopyrite). The last-mentioned is not known to carry precious metal values, but the elsewhere uncommon copper arsenate has been a source of great profit to claimholders. The presence of arsenic has been without appreciable influence in metallurgical practice, because most of it has been volatilised during reduction in the blast furnace, and by modern electrolytic methods of refining the last traces can be completely eliminated from the copper without any trouble.

*Bismuth.*—One of the best informed residents of Cardross tells me that bismuth in traces is regarded as characteristic of Cardross ores; and, in view of its plentiful occurrence (as native bismuth, bismutite, and bismuthinite) at Baker's Camp, and the occurrence of the related magmatic metals tin and tungsten at various points on the field, this would seem not unlikely. A bismuth content of 0·1 per cent. was entered against a parcel of

* The chemical analyses quoted in this report have in a few instances been derived from ore purchase notes of the various Customs smelters and a few from official records, but most of them came from the old assay books of the Mammoth Copper Mines, Limited. Several from the assay registers of Chillagoe Limited were placed at my disposal by the general manager of that company, Mr. James Horsburgh.

ore (from the 50 ft. Caledonia shaft on Plum-tree Creek) purchased by the Electrolytic Refining and Smelting Company during 1916; and I myself have detected it by the iodide test in the highly arsenical mixed sulphide ore of the Laverock and the Premier and in gossan from the Prestwich and the Chieftain. It might have been expected also in the mixed sulphide ores of the L line, but none of the specimens collected by me yield even traces. The metal is present in the ores in too small amounts to affect their reduction in the furnace; but, as a minute trace has a tremendous influence on the quality of the metallic product and quite unfits it for many purposes, it is fortunate that in the modern electrolytic refinery we have a means for the complete separation and recovery of both copper and bismuth.

*Boron.*—The boro-silicate, tourmaline, occurs plentifully and in close association with copper ores at the Mountain Maid and on the Premier. I have also found traces in the decomposed felsite cropping on the Chieftain (though absent from the unaltered rock below), in the mixed sulphides penetrating the dyke rock, and in the chloritic coating separating the sulphides from the unaltered rock, and there are very slight traces in the chloritised gneiss in the rise above the crosscut on No. 4 level. Slight traces were detected also in the greisen from the crop on the Macdonald.

*Calcium.*—The carbonate of lime, calcite, occurs in only very small amount in the lodes of Cardross; and only one vein of the fluoride, fluorspar, has been located. The want of lime is very severely felt in smelting the siliceous ores of Cardross, and a supply of the flux has to be brought from the crops of Silurian limestones some distance off the road to Mungana, and 12 miles distant from the smelter.

*Carbon.*—The element is combined in the carbonates of copper of the oxidised zone, other compounds being rare.

*Copper.*—The commercially most important metal at Cardross occurs in relatively few combinations: with iron and sulphur as chalcopyrite and bornite, with sulphur alone as chalcocite, with arsenic acid as olivenite, with carbonic acid as azurite and malachite, and with oxygen alone in tile ore. None of the ores mined are very high grade, 50 per cent. copper being very rare, 30 per cent. is regarded as exceptional, even in the enriched zone, while the sulphide stopes probably have not averaged above 7 per cent. copper.

*Fluorine.*—The fluoride, fluorspar, and the fluosilicate, topaz, have been found only in outlying sections of the field.

*Gold.*—The presence of gold in the copper ores of Cardross is one of the factors contributing to the continued prospecting and exploitation of the lodes. The proportion is by no means uniform throughout the field, for in the extreme south on Nonda Creek the ores are very low in the metal, while those of the L line are in places exceptionally high. Thus at the Lochinvar ore carrying more than an ounce of gold to the ton has been won; and the Clansman, averaging higher gold than any other holding on this field, has yielded shipping ores carrying from 4 to 20 dwt. per ton.

*Iron.*—The metal is widely distributed: as sulphide in combination with copper in chalcopyrite, with arsenic in arsenopyrite, and alone in pyrite; and, only slightly less plentifully in the lodes, as oxide—in magnetite, limonite, scorodite, and wolframite. There being a deficiency of iron in the shallower ores of Cardross ordinarily mined, and no large bulk of magnetite having been exposed by the relatively insignificant developmental work undertaken thus far below water level, the metallurgist has had to search afield for requisite flux, and has obtained it in the contact deposits on the road to Mungana.

*Lead.*—The sulphide, galena, appears in rare instances, but in such small quantities that it is nowhere recorded in analyses.

*Magnesium.*—Biotite, the magnesia mica, bulks largely in the gneisses of the field.

*Molybdenum.*—Traces of the sulphide, molybdenite, are said to occur in the tin lodes of the Baker's Camp section.

*Phosphorus.*—Phosphoric acid combined with copper has been reported, first in the annual report of the Department of Mines for 1898 and subsequently in the proceedings of the Royal Society of Queensland for 1900. The dark olive-green mineral, encrusting cavities in the oxidised ore, is claimed by old hands on the field to be phosphate of copper, but chemical tests prove it to be arsenate.

*Potassium.*—Muscovite, the potash mica, is an essential constituent of many of the schists, of the pegmatites, and of the greisenised formations.

*Silicon.*—The oxide is present in combination in the fresh and decomposed rock minerals (silicates) of the formation and free as quartz grains and vein fillings. Its excess is the chief obstacle to the profitable treatment of the lower-grade ores.

*Silver.*—Always present in the copper ores and usually in commercially important quantities, the metal is yet in such relatively small amounts that its combinations have not been determined. The oxidised ores carried from 2 to 8 oz. per ton;

and the sulphides now being won are dressed to an average of 8 oz. per ton, which is equivalent to ½ oz. of silver per unit of copper.

*Sulphur.*—This acid-forming element is combined in metallic sulphides and sulpharsenide existing below the oxidised zone. The amount is not metallurgically excessive, and in fact is insufficient to allow of sintering the ore fines, prior to smelting for matte in the blast furnace. The corresponding sulphates are rare, but chalcanthite (hydrous copper sulphate) is to be seen in small quantity in the upper workings and basic iron sulphate may be present in the gossans.

*Tin.*—The oxide, tinstone or cassiterite, is found in the Baker's Camp mines, and it has been recorded from the Admiral. It is likely that the metal is much more widely distributed than has been demonstrated.

*Titanium.*—The oxide of titanium, rutile, has recently been discovered in an alluvial deposit, but the exact locality has not been made public. The magnetite of the Chieftain is not titaniferous.

*Tungsten.*—This rare metal, combined as tungstate of iron and manganese in wolframite, has been located in small quantities, both centrally on the L line and outside in the Baker's Camp quarter of the field. The former occurrence offers a clue as to the origin of the copper ores, but economically it is of little import.

*Zinc.*—The sulphide, zinc blende or sphalerite, is to be seen occasionally in very small quantity in the primary ores; and the presence of zinc in the oxidised ores has been determined chemically, assays recording 1 to 2 per cent. of the metal. Zinc is one of the most obnoxious elements in the eyes of the copper smelter, but the percentages in the Cardross ores are innocuous.

### 2. Occurrence of Minerals.

*Arsenopyrite.*—Mispickel, the compound iron sulpharsenide, occurs in nearly all the lode formations of this field. As minute crystals it is particularly characteristic of the low grade more siliceous portions of the formations, but it occurs in crystalline masses in the kaolinised material, and is seldom altogether absent from the sulphide bodies. In several instances massive blocks have been found at the surface, unaltered except for a thin coating of scorodite. Contrary to expectations, the arsenopyrite is not rich in the noble metals, and some of it is barren, according to assays recorded at Cardross, but arsenical ore from the sink of the Allan shaft on the Albin Macgregor carried (assay book):

Copper, 0·52 %; silver, 1·42 oz. per ton and gold, 7·4 dwt. per ton.

*Azurite.*—The blue carbonate of copper is fairly widely distributed as crystalline platy seams. It is slightly less plentiful than the green carbonate, and open cavities seem to have been essential for its deposition, disseminations being rare. It is more abundant in the Clansman than elsewhere on the L line.

*Bismuth, Native.*—The metal is exploited in the bismuth lodes of Baker's Camp, but it has not been recognised in the copper lodes.

*Bismuthinite.*—Bismuth sulphide occurs at Baker's Camp, but it has not yet been recognised in the copper lodes of Cardross, in which it is most likely present as traces.

*Bismutite.*—Carbonate of bismuth is the chief constituent, economically, of the bismuth lodes of Baker's Camp.

*Bornite.*—The higher grade, secondary copper-iron sulphide, distinguished by a brilliant tarnish, was noticed at only one mine, the Trojan, which differs in other features from the generality of Cardross lodes.

*Calcite.*—Calcium carbonate is of very rare occurrence here, whether in the lodes or in the country.

*Cassiterite.*—The oxide, commonly known as tinstone, is associated with bismuth ores and wolfram in the lodes of Baker's Camp, and the parcel of 1¼ tons consigned from Cardross in 1913 presumably came from there. It has also been recorded as occurring in altered greywacke at the Admiral tin claim (*see* Mineral Index, p. 185).

*Chalcanthite.*—Green sulphate of copper stains are to be seen in several of the old workings.

*Chalcocite.*—The secondary copper sulphide, glance, is seldom seen in the lode outcrops, but it is occasionally found in irregular masses surrounded by earthy malachite. Towards the ground-water level, however, it becomes abundant, there occurring disseminated in the carbonate-bearing liver-coloured limonite ore, and it is even more plentiful in the upper part of the sulphide zone. It has been observed in the Chieftain as far down as the No. 3 level. In all instances it is in the massive metallic form, if we except the doubtful thin, dull, earthy films on exposed surfaces in the zone of secondary enrichment. Chalcocite is generally due to enrichment by descending solutions, and we should expect in practically all cases at no great depth below ground-water level failure of the supply.

*Chalcopyrite.*—The common yellow sulphide of copper and iron, the chief source of copper in the Cardross lodes, occurs in massive form (with and without other mineral inclusions), in

branching aborescent forms, and as fine disseminations. The mineral is normally of primary origin, but there is reason to believe that some of that in the very rich ore just below the zone of oxidation, and part of that found at greater depth in contact with the dyke, may be secondary.

*Chlorite.*—A dull green earth, assumed to be an hydrated compound iron-magnesium-aluminium silicate, is one of the commonest gangue minerals, occurring as a base or cement, as veins and selvages, and as scattered granules in the pure chalcopyrite of the ore-bodies.

*Clay.*—It may be of interest to record here the following partial analysis (from the company's assay book) of the clay at the Cardross brickyard—the result of degradation in situ of schist and gneiss:

Alumina, 31·0 %; ferrous oxide, 6·4 %; and silica, 62·3 %.

*Cuprite.*—The red oxide of copper is noted in G.S.Q. publication No. 134, pp. 13 and 14, as occurring at Arbouin.

*Felspar.*—Orthoclase, potassium-aluminium silicate, is one of the essential constituents of the gneiss, in which it is sometimes developed out of proportion to the associated minerals. Lime felspar, because of the absence of calcareous decomposition products, is probably wanting, but we may assume the existence of soda felspars.

*Fluorspar.*—Calcium fluoride has recently been discovered by Mr. C. Thomason, about a mile to the north of Cardross township, where it forms a small vein in gneiss. By most prospectors the crop would have been passed over as quartz; and a close examination of the very numerous outcrops of the field would probably lead to the discovery of additional deposits. The occurrence of the mineral here, though not in intimate association with deposits of ore, is in support of the conclusions derived from the presence of other pneumatolytic products, such as tourmaline, cassiterite, wolfram, etc.

*Galena.*—Lead sulphide was noticed as small specks in the ore of the Caledonia North, but the occurrence is unusual.

*Garnet.*—This silicate of iron, lime, and alumina, characteristic of metamorphosed sediments of certain composition, was not found in the Cardross area, but numerous minute crystals of the mineral were observed in the gneiss raised from a shaft on Pandanus Creek, near the road to Mungana. Garnet is extremely abundant in the contact deposits of Mungana-Chillagoe.

*Gold.*—Free and visible gold is not now looked for in the Cardross ores, but that the metal is present in commercially

important quantities has already been mentioned in the preceding section.

*Kaolin.*—More or less pure silicate of alumina, derived from the breaking down of the original felspar of the gneiss, is to be met in quantity in most of the formations.

*Limonite.*—Dense massive vitreous or soft dull earthy hydrated oxide of iron is one of the commonest bases in the oxidised portions of the ore-bodies, where it serves as a matrix for the various copper minerals.

*Malachite.*—The green carbonate of copper seldom occurs here except as fine disseminations in a rather dense gossan.

*Magnetite.*—Rounded masses and grains of vitreous, reddish, magnetic oxide of iron are enclosed in the chalcopyrite of the Chieftain ore-body, with every indication of having been the first of the metallic ores to be deposited. The conjunction of chalcopyrite and magnetite is unusual except in contact or apomagmatic ore-bodies, but the latter mineral is acceptable as affording an excess of iron for the convenience of metallurgists operating on ores predominatingly siliceous. The prospect of encountering increased quantities of magnetite in the deeper workings should not be overlooked, as an offset to the undeniably siliceous character of the upper portions of the lodes.

*Mica.*—Biotite, a ferro-magnesian silicate, is an essential constituent of the gneisses, but it seldom appears in the lode formation. Muscovite, the potash mica, occurs as silver-white spangles in the formations, in many cases giving them the appearance of greisen; and crystal spangles, $\frac{1}{2}$ in. in diameter, are common in the more siliceous metamorphics, like those of the Caledonia and Mountain Maid.

*Molybdenite.*—Traces of this sulphide are said to have been found in the Baker's Camp neighbourhood.

*Olivenite.*—Greenish-yellow earthy copper arsenate is the most common oxidation product of the Cardross ores, being the product of reaction between sulphate of copper and arsenate of iron. It occurs in the limonite of the crops, in cellular gossan, and in the kaolinised and micaceous formations, and contains by analyses about 10 per cent. of copper. Already in 1898, as recorded by Mr. Jack, a greenish-yellow powdery ore of the Leicester was known to carry 10 per cent. copper, but it does not seem to have been recognised as arsenate. The crystalline form of the mineral is bright olive-green, and under the magnifying-glass it is seen to have a pearly lustre. It was observed at the Laverock indistinctly drusy in cavities. A dark olive-green vitreous variety was noticed as an encrustation at several mines.

It also is found in a dull pale olive-green lamellar form, filling cracks in still paler scorodite; and some of this has yielded 11½ per cent. of copper. The assay book of the Mammoth Copper Mine, Limited, has an entry, under date 29th June, 1914, recording the analysis of a specimen of copper arsenate as follows:—

Copper, 8·5 %; silver, 45 oz. per ton; gold, 12 dwt. per ton; and arsenic, 20·2 %.

Assuming the copper to have been combined as arsenate, there must have been an excess of arsenic, which probably was united with iron in scorodite. My specimens having been submitted to the Government Analyst for assay, it came to light that Mr. Frank Connah, many years ago, after analysis recognised the material as copper arsenate, but made no public communication on the subject. Moreover, Mr. E. S. Simpson, Mineralogist to the Geological Survey of Western Australia, in his annual report for 1908, records the finding of olivenite (basic arsenate of copper) in fibrous veins and earthy crusts and masses in oxidised ore from the Alice Mary copper mine, Kundip.

Olivenite is described as the commonest of the copper arsenates, but Weed in his "Copper Mines of the World" makes no mention of the mineral having been specially mined as a copper ore in any part of the world, and the interest in the Cardross occurrence should be doubled thereby.

*Pyrite.*—This iron sulphide is a constituent of the ores, sometimes drusy in chalcopyrite, sometimes as crystals up to ¼ in. in diameter, or in ragged nests, but most frequently as thin veins and bands and only exceptionally does it serve as a matrix for the other sulphides. Polished sections of the Chieftain chalcopyrite reveal abundant corroded crystal grains, plainly of greater age than the copper mineral. Cellular masses of crystalline granular pyrite, residual after leaching, lie at grass at the Noonday, where there is also a massive form that exhibits peculiar corrosion surfaces.

*Quartz.*—Crystalline silica is an original component of the gneiss, and it remains in the lode formations even after the more or less complete destruction of the associated felspar and mica of that rock. Part of the secondary quartz, forming veins and a cementing matrix, may have been derived from the decomposition of those silicates but much of it may be of extraneous, that is, magmatic, origin. Quartz crystals ranging from less than $\frac{1}{10}$ in. to more than ¼ in. in diameter and so much as 1 in. long, occur in cavities in the Trojan lode only. Internally they are clear and colourless, but all exhibit a thin opaque white coat.

*Rutile.*—Waterworn crystals (up to ¾ in. in diameter) of this oxide of titanium have been found recently, in gullies about 4 miles to the south-west of Cardross; but nothing has yet been made public as to the nature of the occurrence, and the prospector was absent from the field during my visit.

*Scorodite.*—The arsenate of iron, resultant from the oxidation of mispickel, is conspicuous in the lode outcrops throughout the field, in many as strains or encrustations only, but in some masses weighing tons have been observed (*e.g.*, Caroline, Bonnie Dundee, and Keppoch). It varies in colour from pale sea-green to a dark greenish-blue, and in texture from smooth to vesicular porcelaneous, minutely pearly, drusy, and massive crystalline. The large lumps as a rule have a kernel of unaltered arsenopyrite, specks of which mineral also occur throughout some parts of the scorodite itself. Notwithstanding the low grade of the original arsenopyrite, the arsenate of certain crops has been shown to be rich in the noble metals; and assays made in 1898 are on record of quartz and scorodite from the Leghorn (Albin Macgregor) carrying 1 oz. 2 dwt. of silver with 16 dwt. gold per ton, and of scorodite from the Lebanon (Lochiel and Lochinvar) yielding 5 oz. 16 dwt. silver with 3 oz. 4 dwt. gold per ton.

*Stibnite.*—Antimony sulphide is stated to occur near Callighan's Springs, but, in the absence of directions, I was unable to make a visit of inspection to confirm the report. The mineral is said also to have been found in small quantities in the vicinity of Baker's Camp.

*Tetrahedrite.*—This copper sulphantimonide is noted in G.S.Q. publication No. 134, pp. 13 and 14, as occurring at Arbouin, associated with gold, cuprite, chalcanthite, and ironstone. "Tile ore showing a little tetrahedrite" was reported in 1898 by the Mineral Lands Commissioner to have come from the Ladrone. The presence of antimony in the ores has not been confirmed, and the mineral referred to in both cases probably was chalcocite.

*Tile Ore.*—The earthy red oxide, occurring in the upper parts of the lodes, is locally regarded as tile ore, and probably copper oxide is present in it, but no critical examination has yet been made of the material. "Red iron ore" raised from 39 ft. depth in the Albin Macgregor during August, 1910, carried copper 8·4 per cent., but we know that copper arsenate is present in the red ore of this mine.

*Topaz.*—This fluo-silicate of alumina was observed in crystalline nests in the schists near the Mammoth mine on Pandanus Creek, but it has not been found elsewhere on the field.

*Tourmaline.*—Small rosettes of the brownish-black borosilicate of alumina, iron, &c., are conspicuous in the carbonate ore of the Mountain Maid, and it is also found in the chalcopyrite and pyrite as small nests sending out rays into the surrounding sulphides. At the same mine masses of a hard black rock have been mined with the metallic minerals, and this on close examination proves to be chiefly extremely finely acicular tourmaline, with a little interstitial quartz. Bunches of quartz and ferruginous acicular tourmaline also occur with brown ironstone in a highly arsenical, micaceous, siliceous crop on the Premier. These occurrences offer a clue as to the source of the peculiar hard black and white pebbles in recent stream deposits of the Cardross district. A dark olive-green variety of the same mineral occurs also in ¼ in. radiating rosettes in the gossany formations cropping near the entrance to Callighan's Gorge.

*Wolframite.*—This tungstate of iron and manganese has been found in appreciable quantities at the Clansman and Albin Macgregor, and it is in evidence at Mount Oliphant in the southern part of the field also. The copper ore coming from the Albin Macgregor open cut at times has carried more than 1 per cent. wolfram, and about a ton of the mineral, assaying 53·3 per cent. tungstic acid, has been separated and marketed; but, except for that, all tungsten despatched from the mine has been lost in smelting for copper. Wolframite, partly oxidised and green-stained and accompanied by a little gossany limonite representing oxidised pyrite, is to be seen in granular quartz, cropping in the northern portion of the Clansman. In addition the copper ore shipped from the main workings during 1903 is said to have contained much wolfram.

*Water.*—The Chieftain mine water, on which the continuous running of the central plant has thus far been dependent, is strongly acid, and it contained by analysis, made in October, 1915, 8·19 grains of copper per gallon. No other particulars as to the constitution of the water are available, but the company's register contains the following analyses of boiler scale deposited by water used prior to November, 1913, the date of entry:—

$Fe_2O_3$, 11·0 %; $Al_2O_3$, trace; $CaCO_3$, 48·1 %; $MgCO_3$,, 7·5 %; and $SiO_2$ 33·4 %.

Probably limestone had been used for neutralisation of the contained acid prior to feeding the water into the boiler.

*Zincblende.*—Specks of the sulphide, sphalerite, have been observed in the copper ore coming from the southern part of the L line and also in quartz from the Noonday, but the more general distribution of the mineral is denoted by the analyses quoted elsewhere.

# V. Register of Holdings on the L Line.

This register is restricted to holdings on the L line, whereon developments are being concentrated to the almost total exclusion of the rest of the field. Should the necessity arise it may be enlarged to embrace the many other lines inspected during my visit. Extinct leases as well as those now in force are recorded, but it has not been considered necessary to include as well the forfeited claims.

### Albin Macgregor (M.L. 231).

This lease is often referred to as the Allan, the main shaft having been so called.

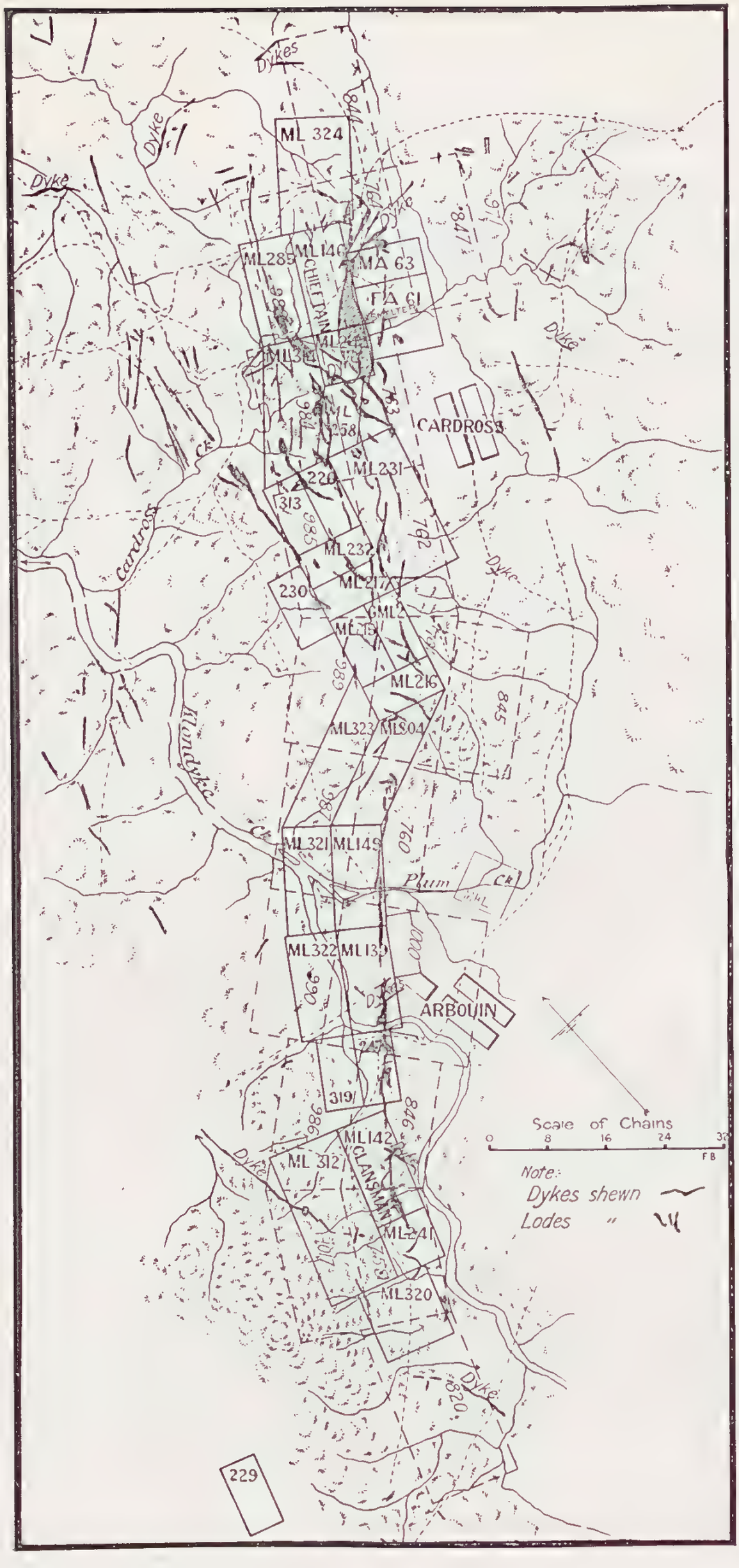
Complete figures of production are unobtainable. The company's assay book, however, shows that the rich carbonate ore won in 1910 assayed copper 12·7 per cent., the decomposed or leached sulphide 11·7 per cent., and black (enriched) sulphide 27·1 per cent.; but the grade of shipments soon fell below these assays, as tabulated below:—

| Year. | Tons. | Cu. | Ag. | Au. | Remarks. |
|---|---|---|---|---|---|
| | | % | Oz. | Dwt. | |
| 1911 .. | 300 | 8·5 | 4 | 4·6 | A.R.D.M., shipments to Chillagoe |
| 1912 .. | 82 5/20 | .. | .. | .. | Mr. Gardiner, value £399 13s. 4d. |
| 1915 .. | 181 10/20 | 4·8 | 2¼ | 6·25 | Company's assay book |

The manager informs me that over 1,000 tons of ore has been despatched from the open cut workings, with contents: Copper 8 to 11 per cent., silver 2 oz., and gold 10 dwt. per ton; and that from the main underlie has come 150 tons of ore carrying copper 9 per cent., silver 4½ oz., and gold 4 dwt. per ton. The oxidised ore (probably arsenate) despatched from the mine during July and August, 1915, assayed:

Cu, 4·8 %; Ag, 2·4 oz.; Au, 6·0 dwt. per ton; FeO, 23·1 %; Insoluble, 44·3 % (of which $SiO_2$, 32·7 %).

In the north-western part of this large lease there are several lode outcrops, besides one series that forms a chain extending diagonally from end to end. On this latter is the main 200 ft. Allan underlie shaft, the 65 ft. air shaft, and the Allan tunnel workings, an open cut and a 60 ft. shaft being on branches of the same. Except for a few potholes and the Allan adit,




Plan of Leases on the L Line at Arbouin and Cardross. With the more prominent Lode and Dyke Outcrops.

exploratory work has been restricted to an area 3 ch. square, on which £5,000 has been spent by the Mammoth Copper Mine, Limited.

The Allan shaft has been sunk on an underlie of 1 in 1 for a total of 205 ft., and levels have been opened up: north 40 ft. and south 150 ft. at 55 ft. vertical depth; south 115 ft. at 70 ft. depth (this is the adit level); south 80 ft. at 100 ft. (filled in); and north 20 ft at 166 ft. (the 1916 tributors' drive), below which the shaft has been filled in. There are leading stopes above the bottom levels, nearly all lode material has been stoped out between the 55 ft. and 70 ft. levels, and above the 55 ft. level south the ore has been stoped up the shaft for 35 ft. and along the drive for 193 ft. Opposite the adit, which is 90 ft. south of the main shaft, a winze has been sunk 50 ft., and there is a drive off it for 28 ft. south, above which high-grade subsulphide ore was stoped to the adit level. Another winze, Reid's tribute, has been sunk 28 ft., about 20 ft. south of the main shaft, and south from it a little stoping has been carried out.

The ore shoot extended a few feet only north of the shaft in each drive. Its stoping length is 110 ft., and its width anything up to 4 ft., but on the average 2 ft. The mine plans show in the 100 ft. level an average of 2 ft. of ore, assaying copper 9½ per cent., with gold 5½ dwt. per ton; in the winze, 20 in. width averaging copper 11½ per cent., with gold 4½ dwt., but smaller and poorer in the bottom; and at the 55 ft. level 2 ft. width, with copper 11 per cent., silver 4 oz. per ton, and gold 8 dwt. per ton. The last assay recorded, from 198 ft. depth and over a width of 8 in., gave copper 8 per cent., with gold 3 dwt. per ton. According to the annual report of the Department of Mines, the reserves in 1911 were calculated at 3,000 tons of 8½ per cent. ore, but this seems to have been an overestimate.

The shaft affords a good idea of the nature of the formation, which shows at the surface as numerous barren branching seams converging below. At the top of the stope, where copper first appeared, 20 ft. from the surface, there shows 3 to 5 in. earthy red ore seamed with greenish-yellow copper arsenate. At 10 ft. above the 55 ft. level the formation again splits up into several leaders, which do not come together until the 166 ft. level is reached, where also secondary sulphides first appear. In the tributers' drive at this level there is exposed 3 in. ferruginous material on the well-defined hanging-wall, then 20 in. formation, and 3 to 6 in. secondary sulphide ore, increasing in thickness downwards.

Crosscutting has given disappointing results at the northern end of the 55 ft. level and farther south in the quartz-veined gneiss and schist of the adit, but it is not unlikely that crosscutting in other parts of the mine may lead to the discovery of other ore-bodies. The ferruginous and slightly cupriferous formation half-way in the adit is worthy of trial.

### Allan (M.L. 226).

Three separate formations crop in this lease, none of any size except at the rather indefinite bunches. That of greatest continuity, on the eastern side of the lease, is highly quartzose, a specially objectionable feature from the metallurgical point of view. The formations cropping in the north-eastern and south-western corners are not unpromising for copper in depth.

### Allan North (M.L. 314).

Several arsenical outcrops traverse this lease, and at the northern end there is a great crop of iron-stained formation, gossany on either wall—a continuation of the Lydian. Copper has not been found in the crops, except in small seams, on which various potholes and cuts have been opened. One shaft has been sunk 15 ft. in carbonate-bearing gossan. The yield of ore has been negligible, but some of the formations are promising for low-grade ore in depth.

### Allan West (M.L. 313).

Small and discontinuous formations appear at the surface in the northern part of the lease and in the south-western corner. The last—a ferruginous, arsenical, micaceous formation, as much as 8 ft. wide in places—is continuous to the north for many chains; and, just beyond the north-western corner, it stands out as a prominent bluff, well worthy of the prospector's attention. It is, in fact, one of the most enticing of the untested crops of this locality.

### Bonnie Dundee (M.L. 242).

The Chieftain formation, here at least 50 ft. wide, is continuous along the eastern side of this lease, though it cuts off against a cross formation just beyond the southern boundary. It is so micaceous as almost to appear a greisen; but in parts it is highly stained by iron and bears much scorodite, especially in the vicinity of a diagonal dyke of felsite.

Except for one or two shallow potholes, no surface work has been done, but the Chieftain stopes extend well into the lease, and a drive at No. 2 level runs almost the whole length

of the lease. In the absence of crosscuts the result of driving has been disappointing, but further driving is to be advocated because of shoots from the fine outcrop probably pitching southwards.

There are other promising arsenical crops on the lease, but their opening up can be postponed until the main formation has been tested.

### Caledonia (M.L. 139).

One small cross leader has been trenched, but the main workings follow a well-defined formation on the eastern side of the lease. This makes no crop in the centre of the lease, but swells towards the south, where there are two felsite dykes.

In the north-eastern corner are an open cut and two shafts, respectively 27 ft. and 60 ft. deep. From the former shaft has come 12 tons of ore, yielding copper 22 per cent., silver 10 oz. per ton, and gold 25 dwt. per ton, while from the open cut came 25 tons of ore with copper 23 per cent., silver 10 oz. per ton, and gold 25 dwt. per ton. The crop in the north-eastern corner of the lease is small, but Mr. Macdonald informed me that a diamond drill hole to the dip of the long cut has proved 10 ft. width of 15 per cent. ore at a depth of 150 ft. There is a fairly large micaceous formation in the southern part of the lease, but the copper shoots at the surface are small, and the gossan seams now showing do not exceed 2 ft. in width.

Alongside Klondyke Creek, near the southern boundary, is a 50 ft. shaft, a little to the north are three small open cuts and a 40 ft. shaft, and after a short interval there are a 35 ft. and a 50 ft. shaft. The Mammoth Copper Mines, Limited, makes a charge of £1,000 against the development of this mine.

The company's assay book registers values of from 1 per cent. to 28 per cent. copper, with ½ oz. to 12 oz. silver, and 0·1 to 1 oz. gold per ton, the highest gold sample having come from the creek outcrop. The oxidised ore, shipped in July, 1915, assayed:

Cu, 2·5 %; Ag, 10·8 oz. per ton; Au, 9 dwt. per ton; FeO, 36·0 %; Insoluble, 39·0 %;

and the sulphide ore shipped in October, 1915, assayed:

Cu, 9·6 %; Ag, 2·9 oz. per ton; Au, 1 dwt. per ton; FeO, 18·5 %; $Al_2O_3$, 15·0 %; and $SiO_2$, 36·0 %.

Mr. E. Markham informs me that in 1899 his party of four for a time made a profit of £50 per man per week, sending 25 per cent. ore to Chillagoe, but that the working of the lode

below water-level was unprofitable. The management credits the creek workings with a production of 700 tons of ore, containing copper 15 per cent., silver 7 oz. per ton, and gold 5 dwt. per ton, but puts the yield of the other workings at a few tons only. Tributers during the last quarter of 1916 cleared £1 per man per day in the 50 ft. creek shaft workings, but of the ore despatched we have few particulars.

| Date. | Tons Ore. | Cu. | Ag. | Au. | Remarks. |
|---|---|---|---|---|---|
| | | % | Oz. | Dwt. | |
| July, 1915 .. | 4·6217 | 2·5 | 10·8 | 9·0 | |
| September, 1915 .. | 53·8875 | 1·7 | 13·7 | 11·0 | Assay book |
| October, 1915 .. | 6·8819 | 9·6 | 2·9 | 1·0 | Assay book |
| October, 1915 .. | 2·1583 | 1·3 | 7·3 | 5·5 | Assay book |
| March, 1916 .. | 10·8272 | 23·0 | 10·1 | 3·2 | Ore purchase note |

### Caledonia Extended (M.L. 321).

One small outcrop of formation was seen near the junction of Plumtree and Klondyke Creeks.

### Caledonia North (M.L. 149).

A formation may be traced along almost the whole of the eastern side of the lease, and in places it has a width of 20 ft. At the crop it is mostly schistose and in parts micaceous and iron-stained, but at a depth it is sulphide-veined.

Caledonia North and Clansman.

To the south of Plumtree Creek there are a number of costeans, too shallow to reveal anything of value; but hereabout No. 2 diamond drill hole, Mr. Macdonald tells me, struck 4 ft. width of dense sulphide ore at 150 ft. depth. Just to the north of the creek is Reid's 75 ft. shaft (flooded), with nearby an open cut and another shaft. Beyond this again is a long open cut, below which the lode has been reached by a 55 ft. block

shaft. Mr. Macdonald informs me that to the dip of the main shaft on Plumtree Creek he has found 5 ft. of 20 per cent. copper ore by diamond drill.

From the creek workings there came 200 tons of ore, assaying copper 14 per cent., silver 8 oz. per ton, and gold 2 dwt. per ton; while from the long open cut came 25 tons carrying copper 20 per cent., silver 10 oz. per ton, and gold 10 dwt. per ton. Work ceased ten years ago because of the then low market value of copper. The dumps are believed to contain 200 tons of low-grade ore (3 or 4 per cent. copper). The ore at the brace of Reid's shaft is a quartzy chalcopyrite with pyrite, blende, and a sprinkling of galena.

### Caledonia West (M.L. 322).

This is a block lease on which no work has been done. There are no lode outcrops on it.

### Chieftain (M.L. 146).

There are in the northern part of this lease several outcrops of no promise, these being indicative of flat seams only; but in the south-east and in the adjacent Bonnie Dundee is the greatest developed formation of the field. Spreading out from a feather edge, on the felsite dyke* in M.A. 63 at the northern end, its width on the southern boundary of the lease is estimated to be more than 200 ft. In parts the crop is indefinitely schistose, quartz-veined and iron-stained, but usually it is micaceous and traversed by gossany bands or stained by scorodite. Much of it is now hidden by the dumps and works, but we know, from the fact that in sinking the first 130 ft. of the main vertical shaft only 7 tons of rich ore was got, that, as a whole, it is only slightly cupriferous above water-level. Below the leached zone is the enriched ore, shoots of which are still being worked, and beneath that are the primary sulphides, the average composition of which, as mined at No. 2 level in November, 1913, is:

Cu, 4·9 %; Ag, 2·6 oz. per ton; Au, 0·5 oz. per ton; FeO, 24·0 %; $SiO_2$, 47·2 %; CaO —; $Al_2O_3$, 10·6 %; and S, 8·7 %.

We are unprovided with a complete record of the production of this mine; but Mr. Macdonald credits the Chieftain with 95 per cent. of the whole output of the Mammoth Copper Mines,

* This dyke is to be seen in several places on the surface and in the underground workings. It is extremely variable in size, it is sometimes wanting in continuity, and it is by no means constant in trend. Its preponderating effect on the localisation of ore deposition has been touched upon already.

VIEWED FROM THE NORTH-WEST.
Bonnie Dundee Hill on Right.

VIEWED FROM THE WEST.
Showing Ore Accumulation Dumps.

VIEWED FROM THE NORTH-EAST.
Smelter on Left.; Engine-House on Right.

VIEWED FROM THE SOUTH-WEST.
Slag Dumps in Foreground.

CHIEFTAIN MINE.

Limited, which is 1,258 tons of copper, 59,472 oz. of silver, and 1,655 oz. gold; and Mr. Gardiner has supplied me with the following partial returns of ore despatched:—

| — | Tons Ore. | Cu. | Ag. | Au. | Value. |
|---|---|---|---|---|---|
| | | % | Oz. | Dwt. | £ s. d. |
| 1911 .. .. | $32\frac{1}{20}$ | .. | .. | .. | 85 9 11 |
| 1912* .. .. | $102\frac{12}{20}$ | .. | .. | .. | 338 5 0 |
| 1916 .. .. | 723 | 14·2 | 6·2 | 2 | .. |
| 1917 (1st quarter).. | $120\frac{5}{20}$ | 18·5 | 8 | 2 | .. |

* The company's assay book records the tonnage raised during April-June, 1912, as $262\frac{5}{20}$ tons, containing: Cu, 9·2 %; Ag, 3·7 oz. per ton; and Au, 3 dwt. per ton.

Under working conditions the loss of a certain amount of ore in the rejects has been unavoidable; and the belt rejects now amount to some few thousands of tons, the coarser material being very low in copper values, while the fines are thought to carry 3 or 4 per cent. of the metal. To be included in reserves also there are other heaps (some hundreds of tons) of low-grade ore, with from 1 to 7 per cent. copper. Some light was cast on the matter of the contents by the letting of a tribute, when the smelter closed down in 1915. The amount of dumped material turned over has not been revealed; but the following record of the product is taken from the official assay books:—

| — | Tons. | Cu. | Ag. | Au. | FeO. | Insol. |
|---|---|---|---|---|---|---|
| | | % | Oz. | Dwt. | | % |
| Firsts .. .. | $16\frac{12}{20}$ | 14·2 | 7·0 | 1·5 | .. | .. |
| Seconds .. .. | $6\frac{13}{20}$ | 9·9 | 5·25 | 1·5 | .. | .. |
| Magnetite and pyrite | $2\frac{10}{20}$ | 5·5 | 2·6 | 2·0 | .. | 10·0 |

The high gold content of the last is due to the pyrite included, silver in this case having followed the copper.

The Chieftain lode formation was first worked as the Macao by Linedale's West Chillagoe Syndicate, and then by the Irvinebank Mining Company. Subsequently the abandoned ground was repegged as the Chieftain by the Scottish North Queensland Exploration Company, and on the liquidation of that concern it passed to the Mammoth Copper Mine, Limited, the present holders. A sum of £16,592 had been spent by the latter company at the end of March last (*fide* Mr. Gardiner); and Mr.

Macdonald estimates that, of the £109,600 worth of ore handled by the company on this field, 95 per cent. has come from the Chieftain.

*Workings.*

The absence of any open cuttings, explained by the leaching of copper from the crop, is the outstanding feature of the Chieftain, the lode having been opened up from three shafts. Linedale's underlie and the underlying air shaft reach only to No. 1 level, but the main vertical shaft is 310 ft. deep.

No. 1 level, at 110 ft. depth, has drives on No. 1 lode, extending 105 ft. north-north-east and 185 ft. south-south-west, but there is only one short crosscut towards the southern end (into the footwall), and that now is inaccessible.

The intermediate level at 131 ft. depth has drives extending on No. 2 lode 15 ft. north and 20 ft. south-south-west, and one 10 ft. long on No. 4 lode connected with the former by a 20 ft. crosscut.

No. 2 level at 160 ft. depth opens with crosscuts 50 ft. east-south-east and 40 ft. west-north-west. Off the former runs a drive for 82 ft. north-north-east on No. 1 lode. Off the latter is a drive north-north-east for 15 ft. on No. 2 lode and drives north-north-east 30 ft. and south-south-west 435 ft. on No. 3 lode. There are an anabranch and several short crosscuts, the longest at the southern end projecting 60 ft. into the hanging-wall. This is below the great crop on the Bonnie Dundee.

At No. 3 level, 225 ft. from the surface, a crosscut runs off for 115 ft. west, and off it is a drive for 205 ft. north-north-east on No. 1 lode, while another runs 340 ft. south-south-west on No. 3 lode. Towards the end of the last are two small anabranches.

No. 4 level, at 305 ft. depth, opens out with a crosscut to the west-north-west for 110 ft., and from near the ends is a drive 90 ft. north-east on No. 1 lode.

*Linedale's Underlie Shaft.*—This was sunk in kaolinised gneiss with red iron seams, in which a small quantity of efflorescent copper sulphate has appeared since the sinking. At about 12 ft. depth the first 3 in. gossan seam commences, and it increases to 12 in. width at 20 ft. depth. This persists to 50 ft. depth, where a slightly steeper head comes down from the roof; and stopes on either side of the shaft prove that ore was won here. At the top of the northern stope there is only 3 in. of gossan containing copper sulphate, but on the southern side there is 6 ft. width of gossan-veined formation. From about 80 ft.

depth, where Linedale's Syndicate was compelled to suspend operations owing to striking heavy water, the underlie of the shaft more nearly approaches the vertical, and the head bounding the stope is left in the roof.

It is known that high gold values were got in the crop at Linedale's underlie shaft, and these are believed to have induced sinking. The assay book has entries under December, 1911, of analyses of the red carbonate ore dump:

> Cu, 4·2 to 4·4 %; silver, 4·6 to 5·5 oz. per ton: and gold, 0·5 to 1·0 oz. per ton;

but another entry gives the dump:

> Cu, 13·4 %; silver, 7·0 oz. per ton; and gold, trace;

and still other cupriferous samples from 40 ft. depth yielded only traces of gold.

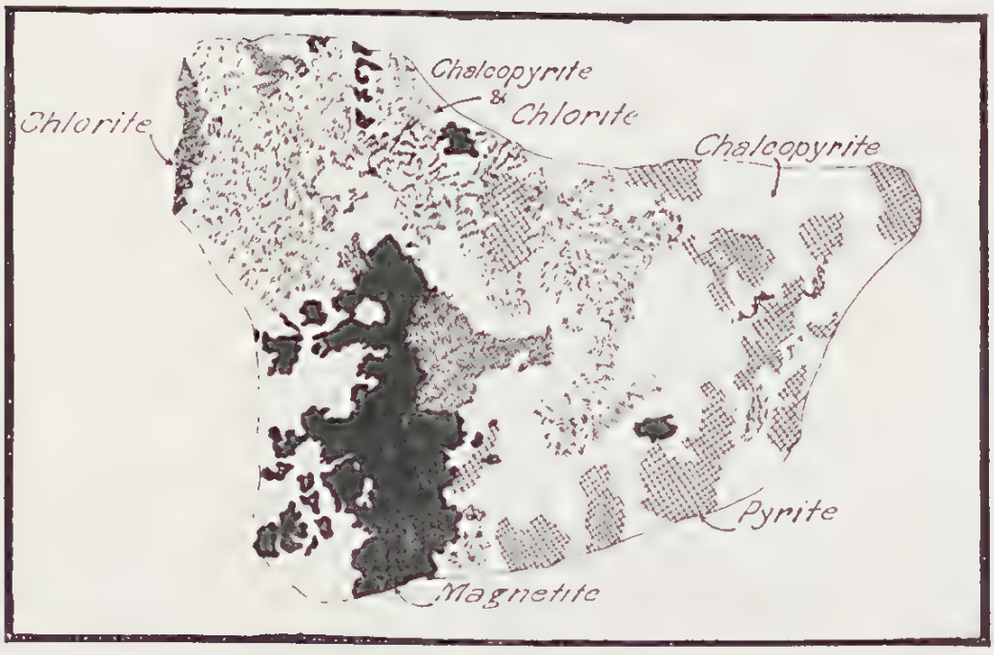
*Air Shaft.*—The outcropping formation consists of a decomposed micaceous material with stringers of siliceous gossan running in all directions. It is said that no copper ore, except slight stains of the arsenate, was met till a depth of 100 ft. had been attained, when suddenly a 12 to 17 ft. body of secondary sulphide ore was struck.

*Main Shaft.*—Payable ore was met at No. 1 level, but in the underlying stope above it there was exposed in March last 10 to 12 ft. width of formation with veins and stringers of ore. The best bunches of ore are got where the country is much crushed, and they die out in the harder crystalline parts, but the average content is about 10 per cent. of sulphide minerals. Two men stoping at that time were recovering ore at the rate of 7 tons per week, and this carried copper 22·6 per cent., with gold 7 dwt. per ton.

On No. 7 level only one lode has been exposed. There are large stopes both above and below the level, and in June ore was being broken down in two superimposed stopes near the shaft. The lower body had been in places, including all branches, 6 ft. wide, but it was then just about worked out; the upper was 2 to 4 ft. wide and averaged 10 per cent. copper; and between the two there was exposed 9 ft. width of 4 per cent. formation. The ore from these stopes consisted of chalcopyrite with earthy blue-black secondary sulphide, the fines from which as bagged at the face averaged 26 per cent. copper. The management, recognising the bunchy and unreliable nature of the rich shoots, proposed to develop the comparatively low-grade intervening formation, and to stope and crush 100 tons of ore per day.

Below No. 1 level the orebody has been stoped out south of the main shaft, but to the north for 20 ft. at least there is still standing 12 to 18 in. of sulphide ore estimated to average 17 per cent. copper.

At No. 2 level there are no stopes on the eastern lodes, but, to the south of the shaft, No. 1 lode has been stoped out both above and below the level, over a length of 240 ft. Beyond the stope to the south the formation continues, but, notwithstanding 12 in. bunches of 20 per cent. ore in places, the average copper content is very low.




Basic Ore, No. 3 Level, Chieftain.

Above No. 3 level south ore has been stoped up from the crossing of the felsite dyke to the southern end of the workings, a distance of 230 ft., and low-grade formation is still in evidence. Under foot there is in places 2 to 3 ft. width of dense magnetic ore rich in chalcopyrite. There is one 55-ft. winze, off which some stoping has been done, but this, being flooded, was inaccessible to me. The management regards this as the best ore in the deep ground remaining for future exploitation.

To the north of the shaft at No. 3 level there are several stopes along the dyke on formations in the nature of stockworks, 3 to 6 ft. wide, with nodular and lenticular masses of magnetite-chalcopyrite ore of all sizes. In June a 40-ft. block of ore was being stoped up along the dyke quite close to the shaft. At the level this showed as 4 ft. of 10 per cent. ore, but 50 ft. above there was 12 to 18 in. of dense chalcopyrite, occurring in intimate association with the dyke rock. Sulphide veins

and bunches occur within the dyke as well as in the adjacent formation, and, towards the top of the stope, formation has been worked beneath the dyke as well as above it. As broken down, the ore averages 5 to 10 per cent. copper. A small proportion is hand picked to average 18 or 20 per cent. copper, and is bagged at the face; but most of the sulphide runs to fines and is recovered in the dressing plant at the surface.

At No. 4 level only comparatively small bodies of ore have been found, and that on the western side of the dyke, to the north of the crosscut, in which direction No. 3 level also was disappointing under foot. To the south of the crosscut and east of the dyke, there is every reason to believe, larger and richer shoots will be found. The best of the ore shoots at No. 3 level undoubtedly are strung along the felsite dyke, and this fact is to be remembered when prospecting in the deeper ground. Too much attention should not be devoted to the ore-bodies dipping off at much flatter angles than the dyke, for they gradually taper out, as in No. 1 north winze below No. 3 level.

### Chieftain North (M.L. 324).

A wide and slightly ferruginous formation, with thin cupriferous gossany seams, crops in the south-eastern corner of the lease, some promising gossan shoads have come from beneath the manager's house, and there are other smaller outcrops along the southern boundary. Half a mile beyond, to the north, copper ore has been uncovered at the Sink-i-loo, but otherwise this would appear to be the northern extremity of the L line. The only work done is comprised in a few shallow trenches along the seams first mentioned.

### Clansman (M.L. 142).

On the Clansman we have again, towards the south at least a formation of more than 50 ft. width and dyke outcrops of prominence. The main workings comprise open cuts and stopes, a main shaft 200 ft. deep, the winze shaft, and Moffat's 60-ft. shaft—all within a space of 4 ch. along the line. Stewart's and Williamson's are block shafts off the main workings, and the Hill shaft, 105 ft. deep, is opposite an opencut in the northern part of the lease.

The ground was originally known as the Lamington, and it was profitably worked from the opening of the field for many years by the Linedale Syndicate and the Irvinebank Company. The Mammoth Copper Mine, Limited, claims to have expended £5,110 on development, and Mr. Macdonald tells me there are hundreds of feet of drives not shown on the mine plans.

The company's plan shows the main shaft to have a depth on the incline of 1 in 1 of 158 ft., and the winze shaft on an incline of 60 degrees to have a depth of 102 ft. Stewart's shaft is given a depth of 75 ft. vertically, and Williamson's 56 ft. Levels are shown at 22 ft., 45 ft., 80 ft., and 125 ft. below the brace of the main shaft, extending respectively 150 ft. north and 35 ft. south (to the open cut), 95 ft. north and 133 ft. south, 20 ft. north and 126 ft. south, and 30 ft. south. Most of the stoping indicated on the plan is between the main shaft and the winze shaft, and above the 80-ft. level. The workings are flooded below the 45 ft. level, where secondary enrichment is just becoming evident. In the old stopes above the level a few pillars have been left standing, and these bear witness that the ore was an earthy gossan with disseminated carbonates of copper, the body nowhere being more than a few feet in thickness. To the north of the main shaft crosscutting revealed a second shoot, about 30 ft. to the east of the main line; and this was stoped by the original holders. The mine was unwatered and sampled in 1913, and the bottom level at 105 ft. depth was extended. (See annual report of the Department of Mines). The lode at that depth was 2 ft. wide, and over a distance of 80 ft. assayed: copper, 20 per cent.; silver, 10 oz. per ton; and gold, 15 dwt. per ton.

No records are extant of the early production of the mine, but necessarily only rich ore could be despatched from the field, and much low-grade material consequently was thrown back into the stopes. Mr. Fred Reid states that 1,000 tons of this old filling, raised and sent to the Cardross smelter in 1915, yielded: copper, 7 per cent.; silver, 4 oz. per ton; and gold, 8 dwt. per ton. The main section is credited by Mr. Reid with a production of 2,900 tons of ore carrying: copper, 20 per cent.; silver, 10 oz. per ton; and gold, 15 dwt. per ton. The yield of the other workings was insignificant. The Clansman ore is peculiar in its high gold content and the associated wolfram. Its nature is revealed in the following analyses, unfortunately incomplete:—

(*a*) Run of mine sulphide ore in the dumps, July, 1912—
Cu, 8·4 %; Ag, 4 oz per ton; Au, 4 dwt. per ton; FeO, 28·2 %; and Insol., 36·0 %.

(*b*) Picked sulphides, raised in December, 1913—
Cu, 20·5 %; Ag, 9 oz. per ton; Au, 11 dwt. per ton; FeO, 47·7 %; $SiO_2$, 2·6 %; $Al_2O_3$, trace; and S, 32·1 %.

(*c*) Oxidised fines, shipped in August, 1915—
Cu, 4·15 %; Ag, 1½ oz. per ton; Au, 5 dwt. per ton; FeO, 12·3 %; and $SiO_2$, 55·2 %.

The Clansman dumps contain some tile ore and green carbonate, and the management believes that 1,000 tons of 3 per

cent. ore could be recovered, 200 tons having already been put through a hand jig, while the "roughs" known to be poor were cast aside.

The country on the Clansman is eye gneiss, with pegmatitic bunches and micaceous aggregates. The formation in parts is slaty, but more often schistose. Above the water-level it is ironstained, below pyrite seamed. The ore shoots are more than usually persistent, but the ore bodies are not to be compared in size with those of the Chieftain.

### Clansman South (M.L. 320).

In the north-eastern corner of this lease is an arsenical formation 12 ft. wide, jutting off a cross dyke of felsite. Gossany bunches in this carry up to 2 per cent. copper, 5 oz. silver, and 5 dwt. gold per ton; while the blue quartz runs 10½ dwt. of gold.

### Danger Hill (M.C.).

This was a claim, formerly held by F. Reid, on what is now the Klondyke lease.

The assay book of the Mammoth Copper Mine, Limited, has an entry under July, 1915, regarding 14 tons of ore assaying: copper, 14 per cent.; silver, 18 oz. per ton; and gold, 8 dwt. per ton. The oxidised ore carried (*fide* F. Reid) 5 or 6 oz. silver per ton, or ½ oz. per unit of copper, whereas the sulphide ore as above assayed 18 to 25 oz. silver per ton, being in the proportion of 1 oz. silver per unit copper. This, however, seems to have been a local reversal of the usual order.

### Furnace Area, No. 61.

The eastern edge of the great Chieftain-Bonnie Dundee crop falls within this holding, and there are others in the vicinity of the assay office, one of which is traceable northwards to beyond the smithy. The last is rather quartzose, but the others are distinctly arsenical.

### Gin (M.C.).

There are a small open cut, two potholes, and a caved shaft, on a north-south trending formation, having a width of 2 ft. This is gossan seamed in parts, and exhibits traces of malachite, but it is not evident that any appreciable quantity of ore was got here.

### Glasgow (M.L. 258).

Two series of outcrops are apparent on this lease. One, on the eastern boundary, bulges in places to 30 ft., but is wanting in continuity, yet low-grade ore is likely to be found on sinking

here. The other, a persistent enmeshed chain, is on the western side. It is arsenical and ferruginous in places, but more often it is highly quartzose, and is known then to be barren of copper, silver, and gold. It is never of large size.

The only excavation is a shallow trench on the indefinite ferruginous siliceous crop in Dundee Gully.

### Glencoe (M.L. 285).

The Glencoe covers a fine outcrop of formation, lying to the north of Cardross Creek. The crop in the northern part of the lease is variable in size, but there is in places 8 ft. width of ferruginous micaceous slightly arsenical and sometimes siliceous crush formation. Towards the south this rises as a low knoll, consisting of ironstained micaceous siliceous gossany and arsenical material, undoubtedly lode formation. The main part of the crop is 60 ft. wide, and formation is found over an additional width of 40 ft., the length being nearly 4 ch.

No work whatever has been done on the crop, notwithstanding its close resemblance to that of the Chieftain lode.

### Glengarry (M.L. 304).

The outcrops are small and of little promise, being mostly quartzose and only slightly ferruginous and arsenical; but quite a number of shallow shafts and potholes have been sunk in addition to the Wild Irishman (35 ft. deep) and Reid's Favourite (65 ft. deep), from the latter of which has come 14 tons of ore assaying: copper, 22 per cent.; silver, 10 oz. per ton; and gold, 2 dwt. per ton. The quartz reefs have been sampled at various times, and that on the north-western side is reputed to carry: copper, nil; silver, ¼ oz. per ton; and gold, ½ dwt. per ton. The cross reefs show up to 3 per cent. copper, 2 oz. silver, and 7 dwt. gold per ton.

### Glengarry West (M.L. 323).

Only one outcrop was observed on this lease. No work has been done.

### Golden King (M.L. 230).

A curved, slightly arsenical, very ferruginous outcrop is to be seen near the middle of the eastern side of the lease, where it is 10 ft. wide; but northwards in the Macdonald and southwards in the Keppoch it contracts rapidly. It is expected to dip into the lease, but no work has been done to test it.

### Golden Link (M.L. 319).

This is a block lease on the Klondyke. There are no outcrops, and no work has been done.

### Herd Laddie (M.L. 241).

The Clansman formation dies out on entering this lease, and, notwithstanding two well marked quartz-felsite dykes, no cupriferous deposit has been discovered, and no work has been undertaken. On the northern boundary there is a 15 ft. hard, ferruginous, schistose, quartz formation of little or no promise.

### Herd Lassie (M.L. 312).

A great felsite dyke crosses this lease, but, contrary to rule, no deposit of any significance has been developed along it. Near the western side of the lease two shafts have been sunk about 10 ft., one wholly in the dyke and one in the kaolinised micaceous footwall country. Some bunches of gossan were got in the latter.

### Keppoch (M.L. 217).

Several formations converge on the eastern part of the lease, where there is a prominent scorodite outcrop, parts of which have yielded as much as 1 oz. gold to the ton. The Keppoch main shaft is on the ore that persists into the adjoining Macdonald lease, and from it has come 320 tons of ore which averaged: Copper, 8 per cent.; silver, 3 oz. per ton; and gold, 9 dwt. per ton. (*Fide* F. Reid.) Other formations to the east, coming in from the Albin Macgregor, have been sunk on to shallow depths.

The company's plan indicates the position of "the main Allan lode" to be in the footwall about 110 ft. to the east of the Keppoch. This is the lode on which is the now flooded windlass shaft.

A sum of £8,000 is said to have been spent by the Mammoth Copper Mine, Limited, on development, mainly in the sinking of the main underlie shaft and driving and stoping off it. The shaft at the time of my visit was accessible to a depth of only 60 ft., but the company's plans give the total slant depth as 207 ft. at 1 in 1. Below water level at 131 ft. vertical depth, the Keppoch lode was left in the hangingwall, and at the 200-ft level a 20 ft. crosscut was required to connect with it. At this same level a drive runs 60 ft. south. Another at the 90 ft. level reaches 20 ft. north, one at the 80 ft. level extends 70 ft. south, and one at the 40 ft. level 30 ft. north to an air-shaft.

Mr. Reid reports the lode to be 4 ft. wide at the bottom, and to average 7 per cent. copper. The assay book has three assays from the 200-ft. level, respectively 26 ft., 34 ft., and 40 ft. from the crosscut: 8·7 per cent., 20·1 per cent., and 12·1 per cent. copper, besides one (of decomposed sulphides at the crosscut

itself) of 18·9 per cent.; but the width sampled is not stated. One 35 per cent. copper sample came from the 80-ft. level, and from the winze below we have two of interest:

Carbonate—Cu, 5 %; Ag, 4 oz. per ton; and Au, 5 dwt. per ton.
Sulphide—Cu, 6 %; Ag, 9 oz. per ton; and Au, 4 dwt. per ton.

At 100 ft. depth in the shaft there seems to have been a separation into hanging and foot-wall lodes with respectively 7·3 per cent. and 3.5 per cent. copper. Three other analyses made in July and October, 1913, are worth quoting, as indicating the nature of the ore stoped. No. 1 is recorded as "oxides" shipped, but presumably the ore was essentially arsenate of copper, the principal product of oxidation at this mine. No. 2 was the run of mine ore from the stopes; and No. 3 was hand-picked ore from the underhand stope:—

No. 1—Cu, 3·1 %; Ag, 4·9 oz. per ton; Au, —; FeO, 25·8 %; $SiO_2$, 31·2 %; and $Al_2O_3$, 17·0 %.

No. 2—Cu, 4·1; Ag, 1·4 oz. per ton; Au, 1·6 dwt. per ton; FeO, 25·0 %; $SiO_2$, 42·0 %; and $Al_2O_3$, 10·6 %.

No. 3—Cu, 15·5 %; Ag, 5·6 oz. per ton; Au, 3·2 dwt. per ton, FeO, 30·0 %; $SiO_2$, 25·3 %; $Al_2O_3$, 14·6 %;

Near the surface in the main shaft there is exposed only an indefinite formation with slight stains of copper arsenate, but there are stopes on either side of the shaft at 12 ft. depth.; and, in the southern face, 25 ft. away, there is to be seen 3 ft. width of kaolinised schist formation, with rich gossany bands up to 6 in. wide, believed to average 5 or 6 per cent. copper and ½ oz. gold to the ton.

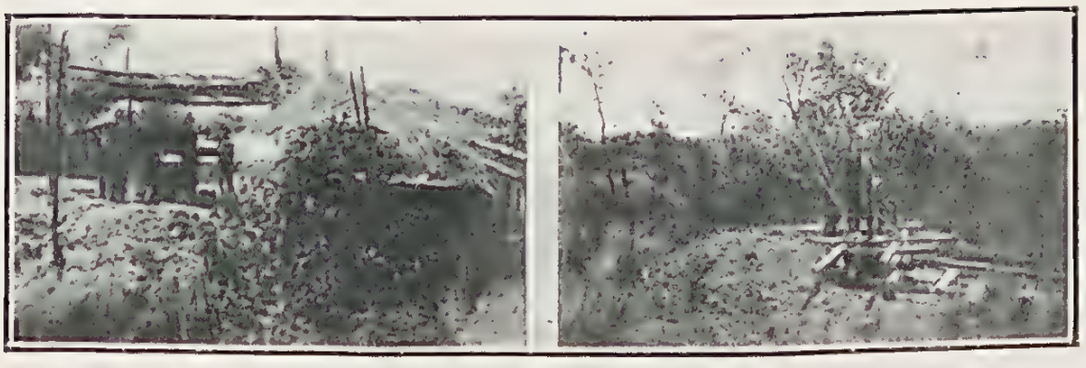
No separate tally of the ore from this mine has been registered by the company.

### Klondyke (M.L. 247).

A claim of the same name and co-terminous with the lease lying between the Clansman and the Caledonian is now in force. Formation is traceable through it with difficulty, but it is nowhere particularly promising, nor are the outcrops persistent. In the north-eastern corner, however, shafts have been sunk: The prospector's, 30 ft.; Reid's, 90 ft.; and Black's, 60 ft.

In the first shaft only floaters were got; and Mr. Reid tells me that he sank his shaft on a 1-in. seam, a surface sample of which had yielded him at the rate of 2 oz. of gold per ton; and that copper did not come in till a depth of 40 ft. was attained. Some stoping was done on a 2 ft. lode above the 60-ft. level and below water-level (at 25 ft. depth); and 56 tons of ore containing copper, 21.4 per cent.; silver, 11 oz. per ton; and gold, 6.5 dwt. per ton was shipped. Water troubles, due to proximity to Klondyke Creek, caused the suspension of operations.

Black's shaft was sunk, without surface indications, to intercept the lode worked by tributers in the creek shaft on the Caledonia; and it entered ore just below the base of the oxidised zone, and 30 ft. below the surface. Sinking had ultimately to be discontinued because of the heavy inflow of water, and 10 ft. above the bottom drives were opened out 5 ft. north-east and 35 ft. south-west. The shoot of ore thereby developed had been stoped out for 25 ft. along the latter drive and up to the 30-ft. level, where it is only 9 ft. long. At the top of the stope the lode has a maximum width of 18 in., but in the face at the 50-ft. level there is only 3 to 6 in. of ore in 5 to 18 in. formation following a defined wall. Thus the prospect of any large quantity of ore being won here is remote, unless new ore-bodies are discovered. Such may be found, for the evidence seems to show that Black's lode is distinct from Reid's, which, dipping much more steeply, should be in on the footwall of the new workings, whereas the Caledonia lode is probably in the hanging-wall.



KLONDYKE AND SINK-I-LOO.

The semi-oxidised ore raised from the top of the stope consists of chalcocite-bearing limonite with some pyrite, while that from the 60-ft. level is chalcopyrite with black facings of the secondary sulphide. The 12 3/20 tons of ore despatched in February of this year carried 19.8 per cent. copper, 12 oz. silver, and 4 dwt. gold per ton; and in April last there was 10 tons more bagged at grass.

### LABRADOR (M.L. 759).

The various formations of this old lease are included in the Clansman, Herd Lassie, Herd Laddie, and Clansman South, except one to the east of the last.

This is an indefinite micaceous formation with gossany seams dipping 1 in 1 west-north-west. Some boulders of scorodite have been got in the shallow cut and pothole, and samples of ore have returned 3·5 per cent. copper with 10 dwt. gold per ton.

### Ladrones (M.L. 760).

Beyond the confines of the Glengarry and Caledonia North there are only small formations, and an indefinite slaty crop with iron-seamed joints. Mr. Jack, in 1898, reported a 6 in. lode of good quality ore, and this was probably the Caledonia North.

### Lamington (M.L. 846).

Beyond the Clansman and Klondyke boundaries no lode crops are to be seen.

The Lamington was one of the first holdings worked on any scale. Mr. Jack, writing in 1898, speaks of an open cutting, on the left bank of Callighan's Creek, showing a width of about 3 ft. of tile ore, siliceous and ferruginous grey ore, and carbonate of copper, said to yield 30 per cent. copper, with rubble giving 6 dwt. of gold per ton. This will have been the old cut on what is now the Clansman.

### Lavater (M.L. 845).

On separate leaders, commonly regarded as the Valley line, there are a 33 ft. block shaft in the northern part and Ramozzi's 25 ft. shaft near the centre of the lease, which have yielded a few tons of auriferous copper ore. Ramozzi's shaft exposes 6 to 12 in. gossany formation, carrying copper arsenate, in kaolinised mica-schist country. The outcrop opposite the block shaft is a 9 in. ferruginous formation with patches of gossan. There are other ferruginous schistose crops near the south-eastern corner peg of the lease; but none of great promise.

### Leander (M.L. 987).

In the south-western corner of the lease, outside of the Caledonia North and Caledonia Extended, there are two crops. One of them, on the northern side of Klondyke Creek, is simply a micaceous formation. The other, on the southern side, is a persistent crop of ferruginous siliceous material, with a width of 5 ft.

### Lebanon (M.L. 761).

Beyond the Lochinvar, Prince Charlie, Lochiel, and Glengarry, part of the Valley series is included in this old lease; and there are a 90 ft. shaft, a 40 ft. shaft, and other shallower holes.

The shafts are nearly all on separate and distinct bodies of gossan, none of them, so far as can now be seen, more than a foot in thickness; though Mr. Reid has reported 1 to 3 ft. width of ore, with 4 to 5 per cent. copper and ½ oz. gold per ton, 10 ft.

above the bottom of the 40 ft. shaft. Carbonates, both blue and green, were got in the 90 ft. shaft; but in the others, including the 40 ft. shaft, the copper was present as arsenate. There is one crop rich in scorodite, a sample of which assayed in 1915 showed only a trace of gold and silver, with no copper; and in the workings also copper was wanting for some feet from the surface.

An outcrop of copper and iron gossan was seen by Mr. Jack in 1898, and an 18 in. vein of good ore showed copper freely.

### Leghorn (M.L. 762).

Exterior to the Albin Macgregor, Macdonald, Keppoch, and Lochinvar, there is one very ferruginous, micaceous, arsenical formation, 2 ft. 6 in. wide, in the extreme north-eastern corner of the lease.

There is also an elbow of the Albin Macgregor-Lochinvar formation, on which is an open cut. The crop is 10 to 15 ft. wide, it is highly arsenical, and is one of the most promising on the field. The work done has been altogether insufficient to prove the nature of the deposit, though the presence of copper arsenate has been demonstrated. This may have been the crop from which Mr. Linedale got 3 oz. gold stone, as reported by Mr. Jack in 1898, though, on the other hand, it may have been one of the many on this hill, the copper ore (tile ore, grey ore, and carbonate), from which assayed 6 dwt. of gold per ton.

### Leicester (M.L. 763 and M.L. 2,080).

Without the confines of the Bonnie Dundee, Glasgow, and Albin Macgregor, there are numerous formations, some persistent, some gossany, and most of them arsenical and quartzose with perhaps gold values; but no work has been done on any of them. At the southern end of the Bonnie Dundee formation, which is gossany in parts, there is much scorodite and some stains of copper arsenate.

### Lexicon (M.L. 989).

All outcrops are included in the Golden King, Prince Charlie, Lochiel, Glengarry West, and Reserve.

### Lily (M.L. 985).

See Albin Macgregor, Allan, Allan Extended, Macdonald, Golden King, Keppoch, Lochinvar, and Prince Charlie.

The Lily of the West is the kaolinised lode on the western side of the Keppoch formation in the Macdonald. From the shallow workings thereon came 6 tons of oxidised ore, despatched in September, 1915.

### Lion (M.L. 984).

There are no outcrops outside of the Allan North, Bonnie Dundee, Glasgow, Albin Macgregor, Allan, and Allan West.

### Lochiel (M.L. 216).

Three formations are known, none of any size or much promise, but all carrying unusual gold values. On the first, which is in the northern part of the lease, is an open cut, whence has come 30 tons of ore assaying: copper, 8 per cent.; and gold, 9 dwt. per ton. On the second, which is known as the slide, is a 65 ft. shaft and cuts that have yielded 25 tons of 12 per cent. ore; and on the third is a 15 ft. shaft, credited with 10 tons of ore containing: copper, 24 per cent.; silver, 10 oz. per ton; and gold, 10 dwt. per ton.

The ore shoots on the first line are up to 3 ft. in thickness, but they are short. The lode is not exposed at the slide, but there is still paddocked a few tons of yellow, brown, and black gossan containing a little azurite and malachite. The third lode is only 3 in. wide at the surface, but it increases below to 1 ft. It shows a little copper arsenate.

### Lochinvar (G.M.L. 2).

The arsenical formations are none of large size, and most are wanting in signs of permanence.

No. 1 whip, the deepest, shaft is 90 ft.; No. 2, the air shaft, is 50 ft.; and Rockley's is 35 ft. deep. These are probably on one and the same line, which again shows of promise in the open cut near the north-eastern corner of the lease. Reid's No. 3 shaft, 50 ft. deep, is on a cross line; and a 60 ft. shaft is on another, which lies parallel with the last. The numerous workings are due not so much to the size of the lodes as to their comparatively high gold contents. The Mammoth Copper Mines, Limited, has £1,000 charged against development here.

No. 1 shaft is credited by the management with a production of 250 tons of ore assaying: copper, 8 per cent.; silver, 3 oz. per ton; and gold, 9 dwt. per ton.; No. 2 shaft with 25 tons assaying: copper, 5 per cent.; and silver, 10 dwt. per ton; and No. 3 shaft with 100 tons assaying: copper, 6 per cent.; silver, 3 oz. per ton; and gold, 13 dwt. per ton. The 60 ft. shaft yielded ore assaying: copper, 10 per cent.; silver, 3½ oz. per ton; and gold, 20 dwt. per ton. From Mr. Gardiner it was learnt that the production of the Lochinvar for 1911 and 1912 was, respectively, 47 5/20 tons of ore, valued at £155 19s. 6d., and 34 7/20 tons of ore, valued at £140 5s. 4d.; and there is still

paddocked at the main shaft about 100 tons of seconds, which contain perhaps 5 per cent. copper (as arsenate). The ore raised during October, 1912, had the following composition:—

Cu, 5·5 %; Ag, 2·5 oz. per ton; Au, 7½ dwt. per ton; FeO, 29·9 %; and Insol., 35·4 %;

while that of July, 1913, contained:—

Cu, 6·9 %; Ag, 7·4 oz. per ton; Au, 5 dwt. per ton; FeO, 32·5 %; $Al_2O_3$, 15·8 %; and Insol., 33·0 %.

At Rockley's shaft the kaolinised formation shows neither copper minerals nor gossan near the surface, but the latter appeared at 10 ft. depth, and the manager expects to meet copper at greater depths. The formation averages 17 per cent. alumina and 3 per cent. silica. The ore-body at the main shaft is reported to have been from 2 to 3½ ft. thick over a length of 100 ft., and to have carried an average of ½ oz. gold per ton. (A.R.D.M. for 1911); but in the faces, according to the assay book, the ore ran from a trace of gold upwards. At the air shaft the lode was 2 ft. wide and uniformly high in gold. The ore-body in Reid's shaft averaged 18 in. at the surface (kaolinised material carrying copper arsenate), but it bulged to 3 ft. below; and the ore as shipped assayed up to 14 dwt. gold per ton, with 3 to 6 per cent. copper, and 1 to 3 oz. silver per ton. The formation in the 60 ft. shaft was as much as 3 ft. wide in places, and it carried masses of copper arsenate. The high gold content of the ore is recorded above.

### L. Reward (M.L. 1,000).

All crops are included in the Caledonia, Caledonia North, and Klondyke.

### Lucifer (M.L. 986).

Nothing is showing except a small micaceous crop in the north-western corner of the lease.

### Lucinda (M.L. 847).

There are small iron-stained silicified formations at either end of this lease, but they do not appear to be of any promise.

### Luna (M.L. 990).

A small quartzose formation of no promise crops on the western boundary of the lease.

### Lydian (M.L. 988).

Outside of the Chieftain, Chieftain North, and Glencoe, the continuation of the persistent Glencoe formation appears

for a few chains beyond the north-western corner, then splitting up and becoming cherty, though still slightly arsenical.

### Lyric (M.L. 1,017).

Except on the Herd Lassie, nothing of moment is showing, notwithstanding the presence of a large quartz-felsite dyke.

### Lytton (M.L. 844).

Near the centre and without the Chieftain North, a small siliceous formation has been observed; and in the extreme north-west there are felsite dykes, and a 2 to 3 ft. crop of micaceous and ferruginous formation. Mr. Jack, in 1898, referred to lumps of good ore on the surface, but of these there is now no sign, and their exact location is unknown.

### Machine Area (No. 63).

The eastern edge of the Chieftain formation falls just within the western boundary of this holding, but northwards, towards and along the great felsite dyke, it becomes rather indefinite. There is also, near the centre, a chain of small quartzose and arsenical crops crossing the lease from south-west to north-east, but these and still other smaller ones are of little significance.

### Macao (M.L. 764).

Exterior to the Chieftain and Chieftain North indefinite formations are in evidence, but they have not been tested in any way.

Mr. Jack, in 1898, quoted two assays from the then newly opened shaft (the old underlie on what is now the Chieftain), with respectively 17 dwt. and 32 dwt. gold per ton. These values were evidently the incentive to the further sinking, which resulted ultimately in the discovery of copper ore in depth.

### Macdonald (M.L. 232).

A number of outcrops are visible on this lease. On the most prominent, there are an open cut and four shallow shafts, whence has come about 50 tons of ore, assaying 1 to 6 per cent. copper, a trace to 3 oz. of silver, and 2 to 10 dwt. of gold per ton.

The Keppoch formation crops along the ridge top, and is at least 12 ft. wide. Near the southern side of the lease only gossan-stained seams show at the surface, but 5 ft. width of lode material has been stoped from 5 ft. beneath the surface. Further north a 12 in. gossany seam was exploited for its contained copper arsenate.

### Premier (M.L. 971).

A number of formations crop on this lease, but none of them appear to be of great continuity. Moreover, they are small, mostly siliceous, and only slightly arsenical.

Two intersecting formations in the south-eastern corner have been trenched, and shown to be 3 to 5 ft. wide; but there is now no copper ore in sight.

### Prince Charlie (M.L. 215).

Three or four formations are exposed on this lease, but no work has been done on them. They are small, and not specially encouraging.

### Puzzle (M.C.).

A 2 ft. siliceous formation crops out on this claim; and lying in the schists at an angle with it is a 6 in. formation, from which has been got a few hundredweight of green carbonate ore. A shallow trench and a pothole have been excavated, but they are insufficient to demonstrate the value of the deposit.

Some chains to the south-east of the above is a very promising, persistent, but untested crop of schistose formation, 3 to 4 ft. wide, with 6 to 9 in. seams of cellular red and brown gossan.

The interest of these occurrences lies in their isolated northerly position relatively to the productive mines of the L line.

### Recruit (M.L. 252).

See Lucifer, Luna, and Leander.

### Reserve (M.L. 253).

See Lexicon and Leander.

### Rita (M.L. 820).

Outside of the Clansman South, one small micaceous crop is to be seen, near a felsite dyke. The 15 ft. Labrador crop continues 2 ch. into this lease, but it has not been attacked.

Two chains to the south of the lease thin gossany seams in micaceous schist have been potholed, but the bunches of ore developed were altogether insignificant.

### Sink-i-loo (M.C.).

The original crop comprised a single iron-stained boulder, and the first traces of copper were found at 18 in. depth. A shaft now flooded has been sunk 16 ft. on an ore-body, of which

the width has varied from a few inches to 2 ft. This has also been trenched for 10 ft. from the shaft. The lode material is finely cellular gossan with blue and green carbonates; and 5½ tons was sold by Mr. Petersen in 1915 on an assay value of 15·8 per cent. copper, 4·8 oz. silver, and a trace of gold. A ton or two more of similar material raised has yet to be disposed of.

The occurrence is of particular interest because of the workings lying on the line of strike of the L line, and more than half a-mile beyond the last productive ground, that of the Chieftain North.

### Valley (M.C.)

The ore-bodies to the east of the L line, on the Leghorn, Lebanon, and Lavater, have hitherto been regarded as on a spur of the main formation, but they are in reality disconnected and distinct from one another.

# VI. Mining and Transport.

The field's remote situation adversely affects the conduct of mining in many ways, and not least in the taxing of the industry by high freights. I have it from Mr. A. Macdonald that the freight on goods sent from Cairns to Cardross has amounted to £10 per ton, including £7 10s. railage to Mungana, and £2 10s. cartage thence to Cardross. As a means of partial relief the Mammoth Copper Mine, Limited, advocates building a branch railway from the Chillagoe Company's terminus; and as a temporary expedient the management has invested in a fleet of seven traction engines and trailers. These, while far more satisfactory than the old horse teams, are not regarded altogether as a success financially, requiring as they do the retention of a trained mechanical staff and the upkeep of a repair shop at Cardross. With loading both ways the cost per ton has been reduced to 8s., and with loading only one way to 13s. The traction engine with two trailers draws a load of about 12 tons (15 tons is the maximum for the road), and, making three return trips, can be depended on to handle nearly 40 tons of concentrate per week, as against the teamster's single trip with say 3 tons. On the grade of ore now being despatched, a traction engine returns a clear profit of £1,200 per year over and above the running charge of £600.

Mining costs may not be called for in a geological report, but the development and exploitation of the ore deposits hangs on them, and it may therefore be of interest to record in passing a few figures that have come to me. The direct cost of sinking a three-compartment shaft has amounted to £8 per ft., but it is believed that, including superintendence and all other expenses, it worked out at £25 per ft. Similarly, with driving the direct underground expenditure was £2 2s. 6d. to £2 10s., but allowing for incidentals the full charge was nearer to £8 or £10. There is little doubt that these costs are unreasonable, and that normally a much better showing could be made, notwithstanding the very real handicaps under which mining is carried on.

The Chieftain is now the sole mine equipped with steam-winding gear and provided with compressor for the air-drills used in mining. The manager tells me that, with ordinary drills requiring two men's attention, the boring amounted to 40 or 45 ft. per day in the formations; but with the "aeroplane" one-

man drill the average is 80 ft., and as much as 100 ft. has been scored in a single shift. Diamond drills have been but little used at Cardross, only three holes having been put down, two on the Caledonia North, and one on the Caledonia, each of them to a depth of 150 ft.

On account of the toughness of the country in the deep ground very little timber is required, and at the Chieftain the depleted stopes have been left open; but, because of their proximity to the surface, the upper stopes at the Clansman had to be filled.

# VII. Treatment.

The subject of treatment may conveniently be subdivided for description, as it is handled by the engineers, into ore dressing or the preliminary mechanical concentration, and smelting or the secondary chemical reduction effected by the application of intense heat.

## 1. Ore Dressing.

The ore has received no mechanical concentration other than rough sorting by hand at any of the mines except the Chieftain, where more up-to-date methods have gradually been introduced by the Mammoth Copper Mine, Limited.

Towards the end of 1913 experiments demonstrated the feasibility of hand-picking the Chieftain ore as in Table I.

Table I.

| Material. | Proportion. | Cu. | Ag. | Au. | FeO. | $SiO_2$. | CaO. | $Al_2O_3$. | S. | — |
|---|---|---|---|---|---|---|---|---|---|---|
| | % | % | Oz. | Dwt. | % | % | % | % | % | |
| Coarse ore .. .. .. | 19 | 10·0 | 4·5 | 1·0 | 44·7 | 18·0 | .. | 5·8 | 19·9 | 99·4 |
| Coarse waste .. .. .. | 37 | 2·4 | 1·1 | tr. | 20·0 | 54·5 | .. | 18·0 | 3·0 | 99·9 |
| Fine pickings (<1½ in.) .. | 4 | 11·2 | 5·4 | 1·2 | 42·0 | 19·0 | .. | 6·0 | 21·2 | 99·4 |
| Fine waste (< 1½ in. > 1 in.) | 7 | 1·9 | 1·0 | tr. | 20·2 | 53·2 | .. | 18·3 | 2·6 | 96·7 |
| Fines (< 1 in.) .. .. | 33 | 8·4 | 3·9 | 1·0 | 33·2 | 31·2 | .. | 9·8 | 15·9 | 98·5 |
| Run of mine, calculated .. | 100 | 6·1 | 2·8 | 0·5 | 30·0 | 38·4 | .. | 12·5 | 11·1 | 98·1 |

With a view to further reduction of costs, mechanical concentration was decided on, following jigging experiments carried out during January, 1914, as summarised in the attached Table II.:—

Table II.

| Material. | Cu. | Ag. | Au. | FeO. | $SiO_2$. | CaO. | $Al_2O_3$. | S. |
|---|---|---|---|---|---|---|---|---|
| | % | Oz. | Dwt. | % | % | % | % | % |
| Run of mine ore .. .. .. | 6·8 | .. | .. | 28·4 | 36·1 | .. | 15·4 | 12·6 |
| Skimmings .. .. .. | 1·2 | .. | .. | 16·4 | 57·6 | .. | 22·0 | 2·2 |
| Hutch fines .. .. .. | 9·8 | .. | .. | 32·0 | 31·6 | .. | 8·4 | 17·8 |
| Raggings .. .. .. .. | 13·9 | .. | .. | 44·3 | 10·5 | .. | 6·2 | 28·1 |

The concentration plant erected at the Chieftain was set in operation in June, 1914, but it closed down on the outbreak of war, and remained idle until early in the present year. The *modus operandi* is as follows: The run of mine ore is trucked from the main shaft to a 200-ton hopper, conveniently situated, whence it drops onto the first grizzly with its bars set 1 in. apart. The oversize is taken up on a picking belt, from which attendants recover bagging ore assaying 17 to 26 per cent. copper, the capacity of the belt being regulated to about 30 tons per man per shift. The rough, poor lumps go to waste; but the seconds from the belt are fed into a coarse cracker, the product from which discharges onto a second grizzly. The oversize from this is caught on a second picking belt, where one man operating to every two on the first belt, recovers missed ore-bearing lumps. These are broken down in a second cracker and fed with the undersize from the grizzlies onto a ½-in. screen; while the waste from the picking belt goes to the seconds accumulation dump.* The coarse from the screen is treated on a hand box-jig and yields a marketable concentrate with a waste product; and the fine, ¼ in. and less in diameter, is elevated to the Hancock jig. Returning now to the first grizzly, the fines drop onto a ½ in. screen yielding: an oversize treated by hand box-jig for a market concentrate and waste; and an undersize, which is run into the Hancock jig. The latter has a maximum capacity of 300 tons per day, but it is being operated at 50 tons; and it yields five grades of concentrate, all of which are shipped. The rejects from the jig are conveyed to the accumulation dump.

The whole of the dressing plant is driven by a 20-30 h.p. gas engine, with attached gas producer running on a coke consumption of 9s. per day.

The 1914 trial was made in connection with the supply of the smelter; and, though the records are incomplete, Table III., compiled from available figures, may be useful.

Thus the low-grade rough waste, with less than 1 per cent. copper, amounted to about one-quarter of the ore from the mine; the hand selected ore, assaying about 10 per cent. copper, to about one-third; and the fine rejects, assaying 1 to 2 per cent. copper, to about one-quarter. It will be noticed that, as conducted on a large scale for the supply of the smelter, the plant gives products differing considerably from those now sought for direct export from the district.

* This now amounts to, say, 5,000 tons of coarse and fine material, the former extremely poor, and the latter averaging 3·4 % copper, so that the average of the whole is very low indeed.

## Table III.

| Period. | Mine Ore. | Rough Waste. | | 1st Belt—Selected Ore. | | | | 2nd Belt—Selected Ore. | | | | 2nd Belt—Discards. | | | | 2nd Grizzly—Fines. | | | | 1st Grizzly—Fines. (Calculated.) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | — | Cu. | — | Cu. | Ag. | Au. | — | Cu. | Ag. | Au. | — | Cu. | Ag. | Au. | — | Cu. | Ag. | Au. | |
| 1914. | | | | | | | | | | | | | | | | | | | | |
| June .. .. .. | Tons.<br>1,520·5<br>100/100 | Tons.<br>261·4<br>17·2/100 | %<br>0·75 | Tons.<br>569·9<br>37·5/100 | %<br>10 | Oz.<br>3·0 | Dwt.<br>0·8 | Tons.<br>96·1<br>6·3/100 | %<br>6·4 | Oz.<br>2·7 | Dwt.<br>0·8 | Tons.<br>349·95<br>23·0/100 | %<br>2·0 | Oz.<br>0·7 | Dwt.<br>0·15 | Tons.<br>113·5<br>7·5/100 | %<br>3·7 | Oz.<br>1·5 | Dwt.<br>0·3 | 8·5/100 |
| July .. .. .. | 2,431·0<br>100/100 | 683·15<br>28·1/100 | 0·75 | 620·8<br>25·6/100 | 10 | .. | .. | 61·3<br>2·5/100 | 7·2 | .. | .. | 651·1<br>26·8/100 | 1·9 | .. | .. | 151·0<br>6·2/100 | 3·2 | .. | .. | 11·8/100 |
| August (1st to 7th) .. | 524·0<br>100/100 | 120·0<br>22·9/100 | 0·75 | 182·3<br>34·8/100 | 8·2 | .. | .. | 9·2<br>1·7/100 | 7·7 | .. | .. | 146·75<br>28·0/100 | 1·3 | .. | .. | 17·5<br>3·3/100 | 3·6 | .. | .. | 9·3/100 |
| Average .. .. | 100/100 | 22·7/100 | | 32·6/100 | .. | .. | .. | 3·5/100 | .. | .. | .. | 25·9/100 | .. | .. | .. | 5·6/100 | .. | .. | .. | 9·8/100 |

## 2. Smelting.

Further reduction than to matte does not concern us here, as conversion to blister copper is not attempted at Cardross.

The water jacket blast furnace, erected in 1912 by the Mammoth Copper Mine, Limited, is 120 in. by 34 in. in section, and the charging floor is 15 ft. above the tuyeres. Its capacity is reckoned at 100 tons of ore per day, with a matte fall of about 4½ or 5 to 1 on a 6 or 7 per cent. ore.

The attached Table IV. contains all pertinent data made available by the management, as to the various smelting campaigns:—

Table IV.

| Campaign. | Ore Treated. | Copper Yield. | Matte Obtained. | Matte Contents. | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Copper. | | Silver. | | Gold. | |
| | Tons. | % | Tons. | Tons. | % | Oz. | Oz. p. t. | Oz. | Oz. p. t. |
| Oct.–Dec., 1912 ... | ... | ... | 252·7 | 100·79 | 39·9 | 5,505 | 21·8 | 82·76 | 0·32 |
| May–Oct., 1913 ... | ... | ... | 412·52 | 136·88 | 33·2 | 6,454 | 15·6 | 252·5 | 0·61 |
| Oct.–Nov., 1913 ... | 2,325·76 | 6½ | 424·67 | 150·78 | 35·5 | 6,841·4 | 16·1 | 243·5 | 0·57 |
| July–Aug., 1914 .. | 2,154·3 | 7 | 453·65 | 151·06 | 33·3 | 7,233 | 15·9 | 206·5 | 0·45 |
| May–Oct., 1915 ... | 8,106·3 | 7¼ | 1,783·7 | 589·3 | 33·4 | 27,792 | 15·6 | 775·5 | 0·43 |
| | | | 3,327·24 | 1,128·81 | | 53,825·4 | | 1,560·76 | |

The first, with an abundance of oxidised ore, was conducted under the severe handicap of insufficient blower capacity. The second and third are stated to have been unprofitable because, in the absence of a metallurgist in charge, the fluxes consumed cost more than the value of the copper produced. The fourth was a complete success and also the fifth, that is to say, as far as the more basic ores were concerned. With regard to the siliceous ores it is thought that it would, perhaps, pay better to ship them to a central customs smelter at Chillagoe or Mungana, where there are basic fluxes, than to carry the requisite fluxes to Cardross.

In the matte of the first campaign copper averaged 40 per cent. and in that of the last 33½ per cent. The silver fell in sympathy from 22 to 15½ oz., but gold, only 0·32 oz. in the first campaign, amounted to 0·61 oz. in the second, though there was later a falling off to 0·43 oz. per ton. The presence of much arsenic in the ores would not seem to have been regarded as a nuisance by the local metallurgists, because most of the element

was volatilised and passed off in the blast furnace fumes. It is recorded that the matte produced 30th July, 1915, carried, with 31 per cent. copper, 2·1 per cent. arsenic; and it is probably to be found also in the flue dust, of which for want of a complete analysis the following, made in November, 1913, is quoted:

Cu, 6·3 %; Ag, 2·5 oz. per ton; Au, 1·5 dwt. per ton; FeO, 17·7 %; $SiO_2$, 13·2 %; CaO, 0·9 %; $Al_2O_3$, —; S, 8·9.

From the company's assay book it is learnt that the average copper content of the slags of 1912 and 1913 was about 0·6 per cent., in 1914 it fell to 0·35 per cent. in one case at least, but in 1915 it gradually increased from 0·4 per cent. in May to 0·6 per cent. in October. The composition of the slag in September of the same year was:

Cu, 0·5 %; Ag, —; Au, —; FeO, 29·0 %; CaO, 19·6 %; $Al_2O_3$, 11·6; $SiO_2$, 38·5 %.

As an example of smelting costs incurred in sending away ore since the Cardross furnace closed down, Mr. F. Reid has submitted to me the purchase note for the ore mined by him while on tribute in the Albin Macgregor. This is dated 26th August, 1916. The gross weight was 21·6745 tons, less 2 per cent. moisture, equal to 21·2410 tons net; and the total value was £290 18s. 11d. (or £13 13s. 11d. per ton), derived as below:

| | | £ | s. | d. |
|---|---|---|---|---|
| Gold = 0·19 oz. per ton × 21·2410 = 4·0357 oz. @ £4 | | =16 | 2 | 10 |
| Silver = 5·23 oz. per ton × 21·2410 = 111·0904 oz. @ 2s. 7·6d. | | =14 | 12 | 6 |
| Copper = 13·58 % | | | | |
| 1·3 | | | | |
| 12·28 % × $\frac{21·2410}{100}$ = 2·6083 tons @ £99 15s. | | = 260 | 3 | 7 |

The charges came to £63 14s. 3d. (or £3 per ton) apportioned as follows:—

| | £ | s. | d. |
|---|---|---|---|
| Returning charge: 260·83 units at 4s. 6d | = 58 | 13 | 9 |
| Port Kembla charges .. .. .. | 1 | 7 | 6 |
| Bundling charge .. .. .. .. | 1 | 1 | 0 |
| Sydney charge (ore bags) .. .. .. | 0 | 8 | 0 |
| Sorting .. .. .. .. .. | 2 | 4 | 0 |

Thus the net value after smelting was £227 4s. 8d. (or £10 13s. 11d. per ton of ore), out of which had to come payment for mining and transport.

For comparison the essentials of an ore purchase note of the Mammoth Copper Mine, Limited, dated 15th July, 1915, is

included. It refers to 13·9565 tons (dry weight) of ore from Danger Hill (Klondyke):

| | £ | *s.* | *d.* |
|---|---|---|---|
| Gold = 8·0 dwt. per ton, less 1·2 dwt. = 6·8 dwt @ 4s. | = 1 | 7 | 3 |
| Silver = 18 oz. per ton, less 2 oz. 14 dwt. = 15 oz. 6 dwt @ 2s. | = 1 | 10 | 7 |
| Copper = 14·05 %, less 2·10 % = 11·95 % @ 11s. 2d* | = 6 | 14 | 3 |
| Gross value .. .. .. .. .. | 9 | 12 | 1 |
| Smelting charges per ton .. .. .. .. | 2 | 10 | 0 |
| Leaving net profit per ton .. .. .. .. | 7 | 2 | 1 |

* *i.e.* @ £82, less £26 = £56 per ton.

Bismuth is not mentioned in either of the above ore purchase notes, but at least one consignment from the Caledonia was debited with 0·1 per cent. of the metal and penalised accordingly by the Electrolytic Refining and Smelting Company, at the rate of 6d. per unit or part thereof.

# VIII. Production

The early production of this field is an unknown quantity. This is partly because of the neglect of many producers to forward returns to the mining registrar, and partly because the Wardens, until recent years, have not reported the output of the Cardross mines separately from those of Chillagoe. In Table V. are incorporated the yearly totals as derived from the annual reports of the Department of Mines.

TABLE V.

| Year. | Ore. | Copper. | | Silver. | | Gold. | | Remarks. |
|---|---|---|---|---|---|---|---|---|
| | | | | Total. | P. t. | Total. | P. t. | |
| | Tons. | Tons. | % | Oz. | Oz. | Oz. | Oz. | |
| 1898 | ... | .. | .. | .. | .. | .. | .. | No returns |
| 1899 | 1,500 | .. | .. | .. | .. | .. | .. | Ore raised |
| 1900 | .. | .. | .. | .. | .. | .. | .. | No returns |
| 1901 | .. | .. | .. | .. | .. | .. | .. | No returns |
| 1902 | .. | .. | .. | .. | .. | .. | .. | No returns |
| 1903 | .. | .. | .. | .. | .. | .. | .. | No returns |
| 1904 | .. | .. | .. | .. | .. | .. | .. | No returns |
| 1905 | .. | .. | .. | .. | .. | .. | .. | No returns |
| 1906 | 400 | .. | 17 | .. | .. | .. | .. | Lamington |
| 1907 | .. | .. | .. | .. | .. | .. | .. | No returns |
| 1908 | .. | .. | .. | .. | .. | .. | .. | No returns |
| 1909 | 363·3 | 40·25 | 11 | 2,556·2 | 7 | 113·75 | 0·313 | Klondyke* |
| 1910 | 103·44 | 14·98 | 14½ | 586 | 5 | 23·32 | 0·225 | Arbouin |
| 1911 | 502·91 | 46·53 | 9¼ | 2,264·76 | 4½ | 78·34 | 0·155 | Klondyke† |
| 1912 | 181·50 | 14·19 | 7 | 778·18 | 4¼ | 38·36 | 0·211 | Ore. Mammoth Co.‡ |
| 1912 | 225·02 | 85·98 | 38¼ | 4,878·14 | 21¾ | 67·99 | 0·302 | Matte. Mammoth Co. |
| 1912 | 162·55 | 17·85 | 11 | 1,610·56 | 21¾ | 11·10 | 0·068 | A. Macdonald |
| 1913 | 872·89 | 283·17 | 32½ | 13,882 | 16 | 517·66 | 0·593 | Matte? Mammoth Co. |
| 1913 | 31·36 | 3·55 | 11¼ | 103 | 3¼ | 10·07 | 0·321 | F. Reid |
| 1914 | 2,154·4 | 158·4 | 7¼ | 7,771 | 3½ | 168 | 0·078 | Mammoth Co. |
| 1915 | 8,090 | 591 | 7¼ | 29,179 | 3½ | 769 | 0·095 | Mammoth Co. |

* Mr. F. Reid informs me that in 1909 he shipped more than 1,000 tons of 20 % ore, of which there is no official record. This came from the Spaniard, Noonday, and Just-in-Time, none of which mines are on the L line described in this report.

† The Mammoth Copper Mine, Limited, produced during the period August to December (kindness of Mr. R. Gardiner): 485 tons 6 cwt. 1 qr. 14 lb. of ore, valued at £1,424 14s. 6d.

‡ The Mammoth Copper Mine, Limited, during the months February to December, 1912, produced (Mr. R. Gardiner): 198 tons 12 cwt. 3 qr. of ore, valued at £878 4s. 3d.

For Table VI., giving the output of the mines of the Mammoth Copper Mine, Limited, from October, 1912, to March, 1917, I am indebted to Mr. Robert E. Gardiner, the secretary to the company.

## Table VI.

| Date of Campaign. | Ore Smelted. | | Production. | | Metal Contents. | | | Gross Value. | Total Realisation. | Nett Value. | Cost per ton Cu. for Realisation. | Product Sent to— | Price of Copper. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | — | Cu. | Matte. | Ore. | Gold. | Silver. | Copper. | | | | | | |
| | Tons. | % | Tons. | Tons. | Oz. | Oz. | Tons. | £ s. d. | £ s. d. | £ s. d. | £ s. d. | | £ s. d. |
| December, 1912 .. | .. | 7 | .. | 61·70* | 5·36 | 229·49 | 4·35 | 348 16 6 | 148 0 0 | 200 16 6 | 30 5 0 | Chillagoe .. | 80 0 0 |
| Oct.-Dec., 1912 .. | .. | .. | 252·70 | .. | 82·76 | 5,505·00 | 100·79 | 8,778 11 6 | 1,930 5 9 | 6,848 5 9 | 19 18 0 | do. .. | 76 0 0 |
| May-July, 1913 .. | .. | .. | 412·52 | .. | 252·47 | 6,453·75 | 136·88 | 10,267 8 10 | 2,798 10 0 | 7,468 18 10 | 20 11 7 | do. .. | 71 0 0 |
| Oct.-Nov. 1913 .. | 2,325·76 | 6¼ | 424·67 | .. | 243·33 | 6,841·40 | 150·78 | 11,777 4 5 | 3,061 3 8 | 8,716 0 9 | 20 8 1 | do. .. | 67 10 0 |
| July-Aug., 1914 .. | 2,154·3 | 7 | 453·65 | .. | 206·35 | 7,232·85 | 151·05 | 10,462 13 5 | 3,828 10 0 | 6,634 3 5 | 25 7 0 | Kembla .. | 60 10 0 |
| May-Oct., 1915 .. | 8,106·3 | 7¼ | 1,783·70 | .. | 775·64 | 27,792·12 | 589·28 | 58,079 2 6 | 19,805 19 0 | 38,273 3 6 | 33 10 2 | do. .. | 89 10 0 |
| June-Dec., 1916 .. | .. | 14¼ | .. | 723·00† | 77·25 | 4,466·0 | 102·88 | 9,420 16 10 | 5,026 9 1 | 4,394 7 9 | 61 13 0 | Lempriere and G. and M. | 102 10 0 |
| Total .. .. | .. | .. | 3,327·24 | 784·70 | 1,643·16 | 58,520·6 | 1,236·03 | 109,134 14 0 | 36,598 17 6 | 72,535 16 6 | | | |
| Jan.-Mar., 1917 .. | .. | 18½ | .. | 120·25 | 12·00 oz.<br>2 dt. p.t. | 952·0<br>8 oz. p.t. | 22·24<br>18½% | 3.351 16 4 | 840 0 0 | 2,511 16 4 | | | |
| Grand Total | .. | .. | 3,327·24 | 904·95 | 1,655·16 | 59,472·6 | 1,258·27 | 112,486 10 4 | 37,438 17 6 | 75,047 12 10 | | | |

* Noonday siliceous ore.

† Chieftain.

ANTHONY JAMES CUMMING, Government Printer, Brisbane.